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Estimating Chinook salmon escapement on the Copper River, 2004 annual report

Annual Report No. FIS 04-503

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ANNUAL REPORT SUMMARY PAGE

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Investigators/Affiliations: Keith van den Broek and Bruce Cain, Native Village of Eyak; Jason J. Smith and Michael R. Link, LGL Alaska Research Associates, Inc.

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EXECUTIVE SUMMARY

The purpose of this project was to use fishwheels and two-sample mark-recapture methods for long-term monitoring of Chinook salmon *Oncorhynchus tshawytscha* escapement on the Copper River. This report summarizes results from the 2004 field season, the fourth year since the project's inception. Objectives in 2004 were to: (1) estimate the annual, system-wide escapement of Chinook salmon to the Copper River using mark-recapture methods, such that the estimate was within 25% of the actual escapement 95% of the time; and (2) develop a long-term monitoring program operated by the Native Village of Eyak (NVE).

For the first sample event, two live-capture fishwheels were operated at Baird Canyon for 1,201 h from 22 May to 22 June. During this period, 2,763 adult Chinook salmon were captured and 2,515 fish were marked (2,017 spaghetti tags and 498 radio tags). For the second sample event, one fishwheel was operated near the lower end of Wood Canyon for 1,284 h from 28 May to 21 July. A total of 3,339 Chinook salmon were captured and 3,101 fish were examined, of which 185 were recaptures. The probability of a fish being marked at Baird Canyon and the probability of a marked fish being recaptured at Canyon Creek were not independent of time. Using a temporally stratified Darroch estimator, estimated abundance of Chinook salmon measuring 600 mm FL or greater that migrated upstream of Baird Canyon from 22 May to 22 June was 40,564 (SE = 4,650). The median travel time of Chinook salmon tagged at Baird Canyon and recaptured at Canyon Creek (~ 91 km upstream) was 9.0 d (range: 4-42 d).

With funding currently approved through 2006, this project has evolved into a successful and potentially long-term monitoring program that has made NVE an integral part of Copper River salmon research. The project has also demonstrated that Federal, State and Tribal agencies can work cooperatively to collect data on Copper River salmon stocks that are used to assess, and potentially improve, current management practices.

INTRODUCTION

The Copper River supports one of the largest Chinook salmon *Oncorhynchus tshawytscha* subsistence fisheries in Alaska. The importance of Copper River Chinook salmon to subsistence and other users has focused attention on the paucity of information about escapement levels and distribution among tributaries. Despite the importance of this fishery, managers have found it difficult to obtain annual estimates of Chinook salmon escapement to the drainage. Many stakeholders believe that escapement indices generated by conventional methods (aerial surveys, sonar and weirs on selected systems) have not adequately assessed the abundance of Copper River Chinook salmon stocks.

From 1999-2004, the Alaska Department of Fish and Game (ADF&G) conducted radiotelemetry studies to derive the first system-wide estimates of Chinook salmon escapement to the Copper River (Evenson and Wuttig 2000; Wuttig and Evenson 2001; Savereide and Evenson 2002; Savereide 2003). Due to the project's high expense, biologists planned to terminate this telemetry-based, escapement-monitoring project after the 2001 season. The possible termination of the radio-tagging project created a need for the development of a long-term program to monitor Chinook salmon escapement in the Copper River.

The use of fishwheels (Meehan 1961; Donaldson and Cramer 1971) and mark-recapture techniques can often be an effective method for estimating Chinook salmon escapement. This technique has been used to generate system-wide salmon escapement estimates on numerous large rivers (Meehan 1961; Donaldson and Cramer 1971; Johnson et al. 1992; Arnason et al. 1996; Link et al. 1996; Cappiello and Bromaghin 1997; Gordon et al. 1998; Link and Nass 1999; Sturhahn and Nagtegaal 1999), and after three consecutive years of feasibility testing, appears suitable for use on the Copper River (Link et al. 2001; Smith et al. 2003; Smith 2004). The purpose of this study was to continue using fishwheels and two-sample mark-recapture methods for long-term monitoring of Chinook salmon *Oncorhynchus tshawytscha* escapement on the Copper River.

Objectives

Overall objectives for this three-year study (2004-2007) were to:

(1) Estimate the annual, system-wide escapement of Chinook salmon to the Copper River using mark-recapture techniques such that the estimate is within 25% of the actual escapement 95% of the time; and
(2) Develop a long-term monitoring program operated by the Native Village of Eyak (NVE).

In 2004, two tagging fishwheels were operated at Baird Canyon approximately 66 km (41 mi) upstream of where the Copper River enters the Gulf of Alaska. In addition, one recovery fishwheel was operated below Wood Canyon (river km, rkm 157) approximately 12 km downstream from Chitina, Alaska. This report documents the methods, results and conclusions from the 2004 field season.

Study Area

The Copper River, which drains an area of more than 62,100 km^2 (24,000 mi^2), flows southward through south-central Alaska and enters the Gulf of Alaska near the town of Cordova (Fig. 1). Between the ocean and Miles Lake (rkm 48), the river channel traverses the Copper River Delta which is a large, highly braided, alluvial flood plain. A relatively high proportion of the Copper River's headwaters are glaciated which results in very high unit discharge (volume per square kilometer of drainage area) and sediment loads (Brabets 1997). From 1988 to 1995, the annual mean discharge on the lower Copper River was 1,625 m^3/s (57,400 ft^3/s), with the majority of flow occurring during the summer months from snowmelt, rainfall and glacier melt (Brabets 1997). Peak discharge in June ranged from 3,650 to 4,235 m^3/s while annual peak discharge ranged from 6,681 to 11,750 m^3/s. Water levels in Baird Canyon typically rise sharply from late May through June, level off in July and then peak in August. Sediment loads cause the water to be unusually turbid and fill the river with numerous ephemeral sandbars and channel braids for most of its length.

Two major channel constrictions in the lower Copper River between Miles Lake and the mouth of the Chitina River (rkm 172) offer the potential to capture substantial proportions of migrating Chinook salmon using fishwheels. Baird Canyon is the first major channel constriction on the Copper River upstream of Miles Lake that is suitable for operating the capture-tag fishwheels (Fig. 2). The east bank of Baird Canyon is a steep, often sheer, rock wall that rises over 600 m (1,970 ft) above the river. The west bank slopes more moderately to a maximum height of 20 m above the river, is densely wooded and has a substrate ranging from sand to boulders. The land beyond the west bank is primarily a wetland area that drains the Allen Glacier to the west. The north branch of the Allen River enters on the west bank and is the only major tributary entering Baird Canyon.

Wood Canyon is the second major channel constriction on the Copper River upstream of Miles Lake and is located approximately 91 km upstream of Baird Canyon (Fig. 3). The lower end of Wood Canyon, below the mouth of Canyon Creek and the lower boundary of the Chitina Subdistrict dip net fishery, was considered a suitable location for operating the recapture fishwheels. The west bank in this area consists mostly of steep rock walls, whereas the east bank is a mix of sand bars, rock outcroppings and rock walls.

Chinook and sockeye *O. nerka* salmon begin to enter the Copper River in early to mid-May, as rising temperatures and water flush the ice from the river. Nearly all Chinook and sockeye salmon enter the river by early August (Merritt and Roberson 1986; Evenson and Savereide 1999; Morstad et al. 1999; Evenson and Wuttig 2000; Sharp et al. 2000). The majority of the Chinook salmon run returns to six main tributaries in the upper Copper River, all of which are upstream of Baird and Wood canyons (Evenson and Savereide 1999; Evenson and Wuttig 2000). Since 1978, ADF&G has operated a sonar system to count salmon at the outlet of Miles Lake. An estimated 669,646 salmon passed the Miles Lake sonar site between 12 May and 1 August 2004 (ADF&G 2004).

The Copper River supports important fisheries for Chinook salmon. From 1999 to 2003, Copper River Chinook salmon harvests averaged approximately 55,318 fish annually (Brase and Sarafin 2004). The majority of Chinook salmon are caught in an ocean commercial gill net fishery that operates from mid-May to the end of July in the Copper River District near the mouth of the Copper River. Inriver personal use and subsistence fisheries occur from early June through September between Haley Creek (12 km downstream of Chitina) and the confluence of the Slana River on the upper Copper River. Recreational rod-and-reel fisheries target Chinook salmon in tributaries of the upper Copper River (mainly the Gulkana, Klutina and Tonsina rivers).

METHODS

Project Mobilization

Hiring and Training

Preferred skills of potential candidates for the fisheries technician positions included: prior experience or formal education in either fisheries science or management, experience in salmon fisheries, experience working in a remote field camp, watercraft operation and maintenance or other technical skills, experience working with Alaska Native Tribes and computer skills or record-keeping abilities. Staff from NVE conducted interviews and screened all the applicants. Seven people were hired for the fisheries technician positions by mid-April, including one returning technician from 2003. ADF&G provided an additional technician to assist at Baird Canyon for the entire season. Preseason training consisted of an overview of the project and NVE policies, first aid and CPR certification, Alaska Water Wise certification, and shotgun maintenance and safety training including bear safety videos. Inseason training focused on fishwheel operation, maintenance and safety, boat operation and maintenance, fish sampling, data recording and basic computer skills.

Permit Requirements

In order to access and operate both field camps and install the fishwheels on the Copper River (including anchoring them to the shore), land-use permits were obtained from the U.S. Forest Service (USFS), Alaska Department of Natural Resources (Division of Mining, Land and Water), Chugach Alaska Corporation, Eyak Corporation and Ahtna Incorporated. Permits were also acquired from ADF&G for fish collection and sampling. All permits were obtained prior to the start of the field season.

Fishwheel Design and Construction

The Baird Canyon fishwheels (fishwheels 1 and 2) were made of two, welded aluminum pontoons (11.6 m long x 0.9 m wide x 0.5 m deep), a 3.7 m long axle, three baskets (3.0 x 3.0 m x 2.1 m) and a tower (6.1 m high) and boom (4.9 m long) assembly that was used to raise and lower the axle. The baskets were designed to fish up to about 3 m below the water surface and were lined with knotless nylon mesh (6.4 cm stretch). An aluminum tank (4.3 m long x 1.5 m deep x 0.6 m wide) for holding captured fish was fitted inside each pontoon. The bottom of each live tank was fitted with windows of extruded aluminum mesh to allow for ample water circulation, and an escape panel fitted to the stern of each tank to prevent overcrowding of smaller sockeye salmon and undersized king salmon.

The Canyon Creek fishwheel (Fishwheel 4) used in 2004 was smaller than the two Baird Canyon fishwheels. This smaller fishwheel was built in April 2003 with the assistance of Johnny Goodlataw (Tazlina, AK) and was used successfully during the 2003 field season. Fishwheel 4 was made of two aluminum pontoons (11.6 m long x 0.6 m wide x 0.5 m deep), four lumber and spruce-pole baskets (2 m long x 1.8 m wide x 0.8 m deep), and a tower assembly designed to raise and lower the axle. In May 2004, the deck of Fishwheel 4 was modified so that the live tanks could be secured by a protective frame rather than a hinge mechanism which was used in 2003. The baskets were lined with knotless nylon mesh (6.4 cm stretch). As with the other fishwheels, each live tank was fitted with windows of extruded aluminum mesh and an escape panel.

A second fishwheel (Fishwheel 3) stored at Canyon Creek over the winter, which was similar in design to the two Baird Canyon fishwheels, was modified during the 2004 field season. The baskets of Fishwheel 3 were shortened so that the fishwheel could operate more effectively in shallow water, similar to Fishwheel 4. The modifications to Fishwheel 3 were not completed until the end of the season and so it did not operate in 2004.

Mobilizing the Field Camps

At Baird Canyon, a cabin that NVE built in the fall of 2001 served as the field camp in 2004. The cabin is located on the west bank of the Copper River approximately 2 km upstream from the upper end of Baird Canyon (Fig. 2), and was supplied by boat or plane from Cordova. The Canyon Creek camp was located on the east bank of the Copper River approximately 12 km downstream from Chitina, which was the same location used during the 2003 season (Fig. 3). The upriver camp consisted of two Weatherport tents and small sleeping tents for crew members and it was supplied mainly by boat from Chitina. Mobilization at both camps was timed to ensure that the fishwheels were operational as soon as the river ice cleared and the first Chinook salmon began migrating past each location.

Camp Communication

The field crews followed a specific communication protocol to ensure that the camps were operated as safely and efficiently as possible. Each camp was equipped with a base-station VHF and several handheld VHF radios, “Iridium” satellite telephones, and a “Starband” satellite internet system that provided continuous high-speed internet access. These systems were powered/charged by an array of 6-V batteries (wired to provide 12-V power) that were charged by solar panels and a gas-powered generator. Every morning at a prearranged time, one crew member from each camp was responsible for contacting the NVE office in Cordova via email to exchange information (e.g., provide daily fishwheel catches, place food and supply orders, arrange flights and crew changes). A majority of camp communications were conducted via the internet, with satellite phones reserved for emergencies and instances where internet was temporarily unavailable. VHF radios were primarily used for communication between technicians during field operations, and with supply crews in transit. The crew was able to communicate camp needs in a timely and cost-effective manner, receive feedback on project operations from senior managers and provide daily catch and tag updates to ADF&G biologists and fishery managers.

Fishwheel Operation and Catch

Fishwheel Site Evaluation and Selection

Suitable fishwheel sites were selected based on water depth, water velocity, accessibility, bankfull width and protection from floating debris and rock fall. For the three large fishwheels on this project, water depths greater than 3 m and velocities ranging from 0.5 to 1.5 m/s (1.6 to 4.9 ft/s) were needed to rotate the baskets at optimal speeds and force migrating fish to travel near shore and into the path of the fishwheels. Narrow, fast-flowing channels tend to concentrate migrating salmon close to shore and are thus preferred to wide, slow-flowing areas. The small, four-basket fishwheel could operate in slower water velocities and shallower depths than the large fishwheels. The basket assembly of Fishwheel 4 could also be raised or lowered as water levels changed throughout the season.

Fishwheel Operation

The fishwheels were installed and operated similar to the methods used in previous years (Link et al. 2001; Smith et al. 2003; Smith 2004). The fishwheels were operated 24 hours per day, except for stoppages when they were being re-positioned or repaired. Fishwheel speed (revolutions per minute, RPM) was determined one or more times each day by measuring the time required for the fishwheel baskets to complete three revolutions, thus mitigating for the effects of temporary surges in water velocity. If fishwheel speed was recorded more than once in a day, the arithmetic mean of the measurements was calculated. Daily water temperature (^{o}C) was recorded at the Baird Canyon camp using a Hobo Pro Data Logger which was programmed to record temperature data hourly throughout the study. This information was then downloaded at the end of the season. Daily water levels (m) at both camps were measured from an aluminum staff gauge that was secured to the canyon wall near the fishwheels.

Fishwheel Catch and Effort

Two forms of fishwheel effort were calculated. First, *daily fishing effort* was computed as the number of hours that a fishwheel operated on a given calendar day from midnight to midnight. Second, *effort for calculating catch per unit effort (CPUE)* was computed as the number of hours that a fishwheel fished to obtain a given day's catch. These two effort values were often not the same for a given day because the live tanks were not always emptied of fish at the exact same times each evening. For example, if fish were last sampled at 2200 hours on day t and last sampled on day t+1 at 2000 hours, then only 22 hours of fishing effort was used to obtain the *effort for calculating CPUE* on day t+1 (assuming uninterrupted fishwheel operation). However, in this example, the *daily fishing effort* on day t+1 would be 24 hours because the fishwheel operated continuously for the entire calendar day. *Effort for calculating CPUE* on day t+1 could also exceed 24 hours if the last sampling session on day t was earlier in the day than the last sampling session on day *t*+1. To calculate CPUE (fish per fishwheel hour), the total number of fish captured on a given calendar day was divided by that day's effort for CPUE.

Escape panels

In order to reduce the potential for high densities and crowding of fish in the live tanks, escape panels were used in the live tanks of all three fishwheels in 2004 (see Photo 6 on p. 84 in Smith et al. 2003). The escape panels consisted of two, adjustable vertical slots in a removable aluminum frame. When installed and opened to the appropriate width (6 to 7.5 cm), the escape panels allow smaller fish (e.g., sockeye and other by-catch species) to easily swim out of the live tanks while retaining Chinook salmon. As a result, the escape panels reduce crowding and the potential for sampling mortalities during high-catch periods as well as the amount of crew labor for handling fish.

Tag Application and Recovery

Two to four times per day, depending on catches, crews at Baird Canyon and Canyon Creek removed all fish in the live tanks of each fishwheel. All adult Chinook salmon were counted, sexed, measured for length, inspected for an adipose fin (a missing adipose fin indicated a coded-wire-tagged, or CWT hatchery fish) and examined for marks, scars or bleeding. Fork lengths (FL), measured from the tip of the nose to the fork of the tail, were collected in 2004. Chinook salmon were transferred with a dip net from the live tanks to a V-shaped, water-filled, foam-lined trough (with a fixed measuring tape) for sampling. Water in the trough was changed repeatedly throughout each sampling session. All other captured fish were identified to species, counted and released.

Tag Application

At Baird Canyon, Chinook salmon greater than 500 mm FL and in good condition were either marked with a radio tag and gray spaghetti tag, or they were marked with a yellow spaghetti tag and right operculum punch. Since the fishwheels were expected to capture more fish than ADF&G had planned to radio tag (~ 500 fish), only a portion of each day's catch was radio-tagged. Once the daily radio-tagging goal was met, the remaining fish were marked with a yellow spaghetti tag and a right operculum punch.

The radio tags were Model Five transmitters made by Advanced Telemetry Systems (Isanti, MN). Each radio tag was identified by a frequency and pulse-encoded pattern. Chinook salmon that received a radio tag were supported in the trough while a radio tag was inserted into the upper stomach using a 45-cm piece of polyvinyl chloride (PVC) tubing. All marked fish received a uniquely-numbered spaghetti tag (Floy Tag and Manufacturing Co., Inc., Seattle, WA) constructed of a 5-cm section of Floy tubing shrunk onto a 38-cm piece of 80-lb monofilament fishing line. Using a 10-cm hypodermic needle (16 gauge), the monofilament was sewn through the musculature of the fish 1-2 cm ventral to the insertion of the dorsal fin between the third and fourth fin rays from the posterior of the dorsal fin. The tag was secured by crimping (1.3 mm crimps) the monofilament line.

Tag Recovery

In addition to the general sampling procedures described above (i.e., counting, recording length and sex, and examining for adipose fin and physical marks), all Chinook salmon caught at the Canyon Creek fishwheels were examined for a radio tag, spaghetti tag and right operculum punch. If a fish was marked, the spaghetti-tag number was recorded. Prior to release, all unmarked fish received a left operculum punch in order to identify them as previously caught at the Canyon Creek fishwheels.

Inriver Abundance Estimate

Conditions for a Consistent Abundance Estimate

Two-sample mark-recapture methods were used to estimate the inriver abundance of adult Chinook salmon above the Baird Canyon fishwheels. These abundance estimates are potentially biased if any of the assumptions inherent to the mark-recapture model are violated (Ricker 1975; Seber 1982). The following assumptions are relevant to this study and are similar to those examined by ADF&G in recent Chinook salmon radiotelemetry studies on the Copper River (Evenson and Wuttig 2000; Wuttig and Evenson 2001; Savereide and Evenson 2002; Savereide 2003, 2004).

Handling and tagging fish did not make them more or less vulnerable to recapture than untagged fish.

There was no explicit test for this assumption because the behavior of untagged fish could not be assessed. Sampling sessions were frequent (minimum of three times per day) to ensure that fish were not retained in the live tanks for long periods of time. Escape panels were used to reduce fish densities in the live tanks, particularly during periods of high sockeye catches. Technicians were trained by experienced biologists on how to handle and sample fish in order to reduce the amount of stress on the fish. Visibly stressed or injured fish were not tagged. Also, the distance between the tag and recapture sites (~ 91 km) was probably sufficient enough to reduce the potential of handling-induced "trap shyness" in tagged fish.

Tagged fish did not lose their tags, and there was no mortality of tagged fish between the tagging and recovery sites.

Only Chinook salmon that received both a primary and secondary mark at Baird Canyon were included in the calculations of abundance, so the chance of a fish losing both marks between sampling events was assumed to be negligible. Similarly, only fish that were examined for both marks at Canyon Creek were included in the analysis. Radio-tagged fish that were not detected at or above Canyon Creek on fixed-station receivers or during aerial-tracking surveys were classified as "failures" and removed (or censored) from the study.

Tagged fish mixed completely with untagged fish between the sampling events.

Studies from 1999-2001 showed equal mixing of tagged and untagged Chinook salmon between the lower end of Wood Canyon and the CSS fishery (Evenson and Wuttig 2000; Wuttig and Evenson 2001; Savereide and Evenson 2002), a much shorter distance than between the Baird Canyon and Canyon Creek fishwheels.

Fish had equal probabilities of being marked or equal probabilities of being recaptured regardless of size or sex.

Sex-selective sampling was tested by comparing the ratio of fish recaptured and not recaptured of each gender at the Canyon Creek fishwheels. To test for size-selective sampling at the fishwheels, Kolmogorov-Smirnov (K-S) two-sample tests (Zar 1984) were used to compare the cumulative length-frequency distributions of: (1) all fish tagged during the first sampling event and all fish recaptured during the second event; and (2) all fish tagged during the first sampling event and all fish examined during the second event (as presented in Bernard and Hansen 1992). If sex-selective sampling was detected, the tests for size selectivity would be performed for males and females separately, otherwise data were pooled for both sexes.

Fish had equal probabilities of being marked regardless of time of capture.

Apart from minor fishwheel stoppages for repairs and moves, fishing effort at the Baird Canyon fishwheels was continuous throughout the study period. Weekly mark rates in the second event were compared using contingency table analysis to determine whether this condition was met.

Marked fish had equal probabilities of being recaptured regardless of when they passed the recapture fishwheel.

Weekly recapture rates in the second event were compared using contingency table analysis. If both the mark rates and recapture rates varied among weeks, and a sufficient number of recaptures were available, a temporally stratified estimator would be used.

Abundance Estimate

A temporally stratified estimator using the method of (Darroch 1961) was used to estimate abundance above Baird Canyon. The computer program SPAS (Arnason et al. 1996) was used to calculate the abundance estimate and standard error.

RESULTS

Project Mobilization

Mobilizing the Field Camps

Baird Canyon

Mobilization of the Baird Canyon camp began on 9 May 2004. At that time, there was deep snow cover (~ 2 m) and considerable river ice remaining above and below Baird Canyon. Two people were flown in from Cordova by helicopter the afternoon of 9 May to clear access to the cabin and check snow conditions for landing a ski plane. Supplies and equipment were sling-loaded by helicopter from the Million Dollar Bridge during several round trip flights. Four flights (SuperCub on skis) from Mile 38 on the Copper River Highway were required on 10 May to transport four additional crew members and supplies to Baird Canyon. On 13 May, several round-trip helicopter flights were used to transport a two-person ADF&G radiotelemetry crew and equipment to Baird Canyon. The ADF&G crew assisted with mobilization efforts and installed two radiotelemetry stations upstream of the Baird Canyon fishwheels.

Considerable effort was required to dig the Baird Canyon fishwheels out of the snow during mobilization (Photo 1). Unfortunately, all six baskets for the two fishwheels were crushed under the weight of the snow over the winter and had to be replaced. Materials for the new baskets were hastily ordered from Seattle and shipped to Anchorage, then trucked to Chitina, and then transported by boat to Baird Canyon. The new baskets were built by the crew at Baird Canyon. Fishwheel 1 started fishing on 22 May and Fishwheel 2 was completely assembled and ready to fish on 31 May. Overall, it took six technicians approximately 12 d to mobilize the Baird Canyon camp and Fishwheel 1. It took about 21 d before both fishwheels were operational.

Canyon Creek

Mobilization of the Canyon Creek fishwheels began on 14 May. A two-person crew transported two trucks, two live tanks, an axle for Fishwheel 4 and camp supplies from Cordova to Chitina via the ferry to Valdez. They were joined by two additional crew members in Glennallen on 15 May. From 15-16 May, several trips were made by truck to transport a boat and camp supplies from storage facilities in Glennallen and Gakona to Chitina. The boat was then used to ferry personnel and equipment from Chitina downstream to the field camp. Fishwheel 4, which was stored at the Canyon Creek camp over the winter, was modified (as described earlier) at the Canyon Creek camp and became operational on 28 May. Mobilizing the single fishwheel and camp took approximately 14 d.

Fishwheel Operation and Catch

Fishwheel Operation

Baird Canyon

Copper River water levels at Baird Canyon in 2004 varied by 3.6 m from 1 June to 22 June (Fig. A-1; Table A-1). Water levels increased throughout June, showing the most dramatic increase from 17-22 June (+2.5 m). From 22 May to 21 June, while fishwheels were operational at Baird Canyon, average water levels at the Million Dollar Bridge (located at the outlet of Miles Lake) were 0.8 m above the 1982-2003 average (Fig. A-2). Water levels were 1.1 m above average from 22 May to 21 July when the Canyon Creek fishwheel ceased operation. Water levels at the Million Dollar Bridge were above the historical average for 59 d of the overall 61-d study, and exceeded the record high water levels on 19 d. Average daily water temperature at Baird Canyon ranged from 6.2 to 10.9 ^{o}C from 24 May to 22 June (Fig. A-1; Table A-1).

Fishwheel 1 began fishing at Site 2 along the east bank of the Copper River at the upper end of Baird Canyon at 1030 hours on 22 May (Fig. 2; see Table B-1 for a description of the fishwheel sites used in 2004). Due to increasingly high water levels throughout the sampling period, the fishwheel was fished close to shore and lines securing the fishwheel were regularly adjusted. Fishwheel 1 was shut down for 9 h on 10 June and 19 June to repair basket damage incurred from heavy debris and ice. Fishwheel 1 was stopped for the season at 0725 hours on 22 June due to extreme high water conditions. Fishwheel 1 operated for 717 h from 22 May to 22 June, or 96.7% of the time it was in place (Fig. B-1; Table B-2).

Fishwheel 2 began fishing at Site 3 on the west bank of the Copper River directly across from Site 1 at 1450 hours on 31 May (Fig. 2; Photo 2). This was a suitable site for the duration of the study until extreme high water prevented fishing and safe relocation of the fishwheel. Fishwheel 2 was stopped for the season at 1345 hours on 20 June. Fishwheel 2 operated for 467 h from 31 May to 20 June or 97.4% of the time. Fishwheel speed averaged 2.0 and 1.8 RPM for fishwheels 1 and 2, respectively (Fig. B-1; Table B-2).

Canyon Creek

Water levels at the Canyon Creek fishwheels varied by 2.7 m from 6 June to 21 July (Fig. A-1; Table A-1). Water temperature was not recorded at Canyon Creek. Fishwheel 4 became operational at Site 8 at 1111 hours on 28 May. Site 8, which was very effective at capturing Chinook salmon in 2003, was located along a gravel bar on the west bank of the Copper River approximately 500 m downstream from the mouth of Canyon Creek (Photo 3). A 6-m long aluminum plank was used to hold the fishwheel off the bank and keep it fishing in deep water. On a regular basis the fishwheel was moved in or offshore, and the basket assembly was raised or lowered, to keep the baskets fishing as close to the river bottom as possible. On 7 June, the fishwheel was moved 2 m downstream. On 22 June, the river had reached a level where the gravel bar at Site 8 became completely submerged and the fishwheel was no longer catching fish. The fishwheel was then moved to Site 10, located directly in front of the camp along the east bank of the river approximately 3 km downstream from the mouth of Canyon Creek. On 5 July, the fishwheel was moved 2 m downstream. Fishwheel 4 was stopped for the season at 0747 hours on 21 July. Fishwheel 4 operated for 1,277 h from 28 May to 21 July (98.8 % of the time) and averaged 4.4 RPM (Fig. B-1; Table B-2).

Fishwheel Catch and Effort

Baird Canyon

A total of 2,756 adult Chinook salmon were captured at the Baird Canyon fishwheels. Fishwheel 1 captured 1,503 (55%) fish from 22 May to 22 June and Fishwheel 2 captured 1,253 (45%) fish from 31 May to 20 June (Fig. 4; Table C-1). Daily catches of Chinook salmon exceeded 100 fish on 26 May, and from 29 May to 7 June, 11-14 June and on 17 June. Daily catch peaked at 192 fish (53 in Fishwheel 1, 139 in Fishwheel 2) on 1 June. Daily CPUE peaked at 5.6 fish per hour on 30 May at Fishwheel 1 and 6.6 fish per hour on 31 May at Fishwheel 2 (Fig. 5; Table C-1).

Sockeye salmon catches were low at Baird Canyon (1,375 in Fishwheel 1 and 96 in Fishwheel 2) as a result of using escape panels in the live tanks (Fig. 6; Table C-2). Other species captured included 1 whitefish *Coregonus nelsoni*, 1 Pacific lamprey *Lampetra tridentata*, and 1 steelhead *Onchorhyncus mykiss*.

Canyon Creek

A total of 3,339 Chinook salmon were captured at Fishwheel 4 at Canyon Creek from 28 May to 21 July (Fig. 4; Table C-1). Daily catch peaked at 235 fish on 2 June. Daily CPUE peaked at 9.7 fish per hour on 2 June (Fig 5; Table C-1). There were three main pulses of Chinook salmon migrating past the Canyon Creek fishwheel (28 May to 9 June, 10 June to 21 June and 1-21 July), although the third pulse was relatively minor in comparison. Sixty-seven sockeye salmon and 2 suckers were also captured (Fig. 6; Table C-2).

Tag Application and Recovery

Tag Application

Of the 2,763 adult Chinook salmon captured at the Baird Canyon fishwheels, 2,515 (91%) fish were marked and released (Table 1; Fig. 7; Table D-1; Photo 4). Of these marked fish, 2,017 (80%) received a spaghetti tag as the primary mark and 498 (20%) received a radio tag. The number of marks applied on a single day peaked at 172 (129 spaghetti tags, 43 radio tags) on 1 June. A total of 248 fish were not marked because they escaped prior to being sampled (103), were injured or visibly stressed (142), were coded-wire-tagged (1) or were mortalities (2).

Tag Recovery

Of the 3,339 Chinook salmon captured at the Canyon Creek fishwheels, 3,101 (93%) were examined for both primary and secondary marks (Table 2; Fig. 7; Table E-1). Of those examined, 185 (6%) were recaptures, or fish that were marked at the Baird Canyon fishwheels.

The first two marked fish were captured at Canyon Creek on 1 June (tagged on 25 and 27 May); while the last marked fish was captured on 19 July (tagged on 14 June). The number of fish examined for marks at Canyon Creek peaked at 224 fish on 2 June, and the number of recaptures peaked at 21 fish on 17 June. A total of 238 Chinook salmon escaped prior to being examined for both marks.

Travel time

The median travel time of fish tagged at Baird Canyon and recaptured at Canyon Creek was 9 d (mean = 11.6 d, range = 4-42 d, n = 185, Fig. 8). Migration rates between Baird Canyon and Canyon Creek ranged from 2-23 km/d. The average travel time for radio-tagged fish (13.7 d, n = 33) was not significantly different (two-tailed *t*-test; P = 0.05) than the average travel time for spaghetti-tagged fish (11.1 d; n = 152).

Inriver Abundance Estimate

Censored Tags

A total of 38 fish in the first event were censored from abundance calculations (Table 1). Only two marked fish at Baird Canyon (1 spaghetti tagged and 1 radio tagged), and none at Canyon Creek, measured less than 600 mm FL. Since there was essentially no information on the probability of capture of these fish, an abundance estimate that included these size classes could not be calculated without bias. As a result, only fish measuring 600 mm FL or greater were included in abundance calculations. In addition, 36 radio-tagged fish were classified as "failures" by ADF&G because they were never detected at or above the Canyon Creek fishwheels on fixed-station receivers or during aerial-tracking surveys.

Conditions for a Consistent Estimator

The probability of capture for fish at Canyon Creek appeared to be unaffected by the handling and tagging procedures at Baird Canyon. Recapture rates of spaghetti-tagged (7.5%) and radio-tagged fish (7.2%) were not significantly different ($\chi^2 = 0.08$, df = 1, P = 0.78; Table E-1). Unlike previous study years, the tag number of marked fish released and later recaptured at the Baird Canyon fishwheels was recorded. Using these data, we calculated the migratory delay between capture events at Baird Canyon (Fig. 9). Of the 161 fish captured twice (115 spaghetti tagged and 46 radio tagged), 93 fish (58%) were recaptured within 1 d of being tagged, and the longest migratory delay was 14 d. We assumed that these migratory delays had no affect the abundance estimate. Tag loss and natural mortality were assumed to be negligible between the sampling events. No tagged fish captured at Canyon Creek had shed their spaghetti tag.

Tagged fish appeared to move equally between banks after release ($\chi^2 = 5.19$, df = 2, P = 0.07; Table E-2). Of the 1,136 fish tagged on the west bank that were considered available for recovery, 63 (5.5%) were recaptured on the west bank and 7 (0.6%) were recaptured on the east bank. Of the 1,341 fish tagged on the east bank and available for recovery, 103 (7.7%) were recaptured on the west bank and 12 (1.1%) were recaptured on the east bank. There was a significant difference (χ^2 = 5.18, df = 1, P = 0.023) in the recapture rates of fish released on the west bank (6.2%) and fish released on the east bank (8.6%; Table E-3).

Recapture rates for male (7.7%) and female (7.2%) fish were not significantly different (χ^2 = 0.31, df = 1, P = 0.58), indicating that the probability of a fish being recaptured was not influenced by gender. As in 2002 and 2003, length distributions for marked and recaptured fish were not significantly different (D_{max} = 0.07; n = 2,474, 184; P = 0.32) in 2004, whereas those for marked and examined fish were significantly different (D_{max} = 0.057; n = 2,474, 3,100; P = 0.00; Fig. 10). Based on hypothesis tests described in Bernard and Hansen (1992), these data suggest there was no size-selectivity during the second event but there was during the first event (a Case II scenario). However, there was no significant difference (D_{max} = 0.04; P = 0.89) in the length distributions of fish examined and recaptured at Canyon Creek. This latter test provides no evidence to reject the equal probability of capture assumption. Regardless, there was no need to stratify the data by length to estimate abundance.

Similar to 2003, the probability of a fish being marked at Baird Canyon in 2004 was not independent of time of capture (χ^2 = 92, df = 3, P = 0.00; Table 3). Recapture rates were also significantly different over the 2004 study period (χ^2 = 23, df = 3, P = 0.00), indicating that the probability of a fish being recaptured at Canyon Creek was not independent of time.

Abundance Estimate

One potential source of bias identified by the tests of consistency was unequal capture probabilities over the study period. Therefore, a temporally stratified estimator using the methods of Darroch (1961) was used to estimate abundance. The estimated inriver abundance of Chinook salmon measuring 600 mm FL or greater that migrated above Baird Canyon from 22 May to 22 June was 40,564 (SE = 4,650; Table 4). This estimate was based on 2,477 tagged fish available for recapture (2,016 spaghetti tagged, 461 radio tagged), 3,101 fish examined for tags and 185 recaptures (152 spaghetti tagged, 33 radio tagged).

DISCUSSION

Project Mobilization

Unlike in 2002 and 2003, there was little uncertainty in the days leading up to the 2004 field season about when to mobilize the field camps. A reconnaissance flight over Baird Canyon on 15 April made it clear that snow removal was going to be a major effort and that mobilization was likely going to take longer than in previous years. In 2004, the first fishwheel began operating at Baird Canyon after 12 d, but complete mobilization of the camp and both fishwheels took 21 d. This was considerably longer than mobilization at Baird Canyon in 2002 (14 d) and 2003 (7 d). Additional time was required in 2004 relative to previous years in order to re-build the baskets that were damaged by the weight of snow that had accumulated on them over the winter. At Canyon Creek, mobilization took 14 d in 2004 (14-28 May). This was similar in duration to the mobilization time required in 2002 (10 d) and 2003 (10 d). Since there was no on-site storage at the Canyon Creek camp like there was at Baird Canyon, all equipment had to be transported from storage facilities in Cordova, Glennallen and Gakona. This was done successfully in less than 2 d. The timing and execution of mobilization at both camps was suitable given the environmental conditions in early May 2004.

Fishwheel Operation and Catch

Fishwheel Site Evaluation and Selection

In 2004, all project fishwheels were shut down earlier than scheduled and prior to the end of the Chinook salmon run due to unusually high water levels. For the majority of the period from 20 June to 23 July, stage height of the Copper River exceeded the highest levels recorded in the past 22 years. At Baird Canyon, water levels and velocities at Site 2 and Site 3 became too high to effectively (and safely) operate the fishwheels after 22 June. Investigators were unable to safely transport the fishwheels upstream of the canyon at that time so the fishwheels were stopped for the season. At Canyon Creek, the gravel bar at Site 8 became fully submerged on 22 June and the Fishwheel 4 was moved to Site 10 adjacent to the camp. Although the high-water levels observed in 2004 were considered anomalous, it is important that measures be taken to avoid having to shut down the fishwheels prior to the end of the run in future years.

At Baird Canyon, fishwheels 1 and 2 should be operated at sites 2 and 3 to start the season. If at some point during the season water levels are anticipated to rise to levels observed in late June 2004, then both fishwheels 1 and 2 should be immediately moved upstream of the cabin. In doing so, investigators will still have the option to operate the large fishwheels at more suitable high-water sites, if any are available, upstream of Baird Canyon. In addition, a small, subsistence-style fishwheel will be built in 2005 that might be more suitable during high water than the larger fishwheels. The new fishwheel will likely operate at a site located on the west bank of the river near the Baird Canyon cabin. At Canyon Creek, it is recommended that Fishwheel 4 continue to operate at Site 8 until the gravel bar becomes submerged. The newly modified Fishwheel 3 should operate effectively near Site 8 along the same gravel bar in 2005. At both Baird Canyon and Canyon Creek, it is recommended that potential high-water sites be assessed in 2005.

Fishwheel Catch

Over the entire season, catches of Chinook salmon at the Baird Canyon fishwheels were 23% greater in 2004 (2,763 fish) than catches in 2003 (2,251 fish). Over the same operational period (22-May to 22-June), 64% more Chinook salmon were captured in 2004 (2,763 fish) than in 2003 (1,689 fish). Daily catch peaked at 192 Chinook salmon on 1 June in 2004 whereas the highest daily catch was 156 fish (3 June) in 2003. At Canyon Creek, Chinook salmon catches increased by 73% in 2004 (3,339 fish) relative to 2003 (1,928 fish), despite the fact that only one fishwheel was used in 2004. The high Chinook salmon catches in 2004 highlights the advantage of using a small, subsistence-style fishwheel at Canyon Creek that is able to operate in relatively shallow sites along gravel bars. One reason for the high catches in early 2004 at both locations was that water levels were relatively high and the fishwheels operated effectively. In addition, project investigators used their experience from the previous three years to better position and operate the fishwheels throughout the season.

Inriver Abundance Estimate

One challenge of this project was to capture enough Chinook salmon to generate mark-recapture estimates from an expected population of 40,000 fish that migrated over a period of two months through widely fluctuating water conditions. In 2004, the number of fish marked at Baird Canyon (2,477 fish) and examined for marks at Canyon Creek (3,101 fish) met or exceeded the target levels. More importantly, the number of tagged fish recaptured at Canyon Creek (185 fish) was sufficient to develop an unbiased and reasonably precise abundance estimate (coefficient of variation measured at 11% of the estimate). Estimated annual catch rates (% of run captured) were 3.4% for Fishwheel 1 and 2.9% for Fishwheel 2 at Baird Canyon, and 7.7% for Fishwheel 4 at Canyon Creek. These rates were comparable to those reported for a similar fishwheel project on the Nass River where on average from 1994 to 2001, 4.4% (range: 0.4-9.1%) of the Chinook salmon run was captured in each fishwheel (Alexander and Bocking 2002). The Copper River's high gradient and velocity (forcing fish to migrate close to the banks) combined with turbid water make it an excellent location to use fishwheel technology and mark-recapture methods.

An ongoing challenge of this project is to achieve sufficient catch rates across the entire Chinook salmon migration (both across time and over all fish sizes). In 2004, flow-related changes in fishwheel catchability during both sample events contributed to variability in capture probabilities over the run. Similar effects of river discharge on capture probabilities at fishwheels have been reported elsewhere (McPherson et al. 1996; Cappiello and Bruden 1997; Pahlke 1997; Hebert and Bruden 1998; McPherson et al. 1999; Hewitt and Hightower 2002). At low river levels, capture probabilities are usually low, and this may be because water velocities are not fast enough to force migrating Chinook salmon nearshore (and into the path of the fishwheel) or to rotate the baskets at sufficient fishing speeds. Conversely, capture probabilities tend to be low at some good medium-flow sites during high-water conditions because fish are more likely to swim beneath the reach of fishwheel baskets as depth increases.

Highly variable catch rates at both capture and recapture locations necessitates temporal stratification and, without an increase in catch, reduces the precision of estimates. This can be addressed by increasing fishing power to increase the overall proportion of fish captured and tagged (which would ameliorate the effects of stratification) or by stabilizing the catch rates from the existing fishwheels and sites. We believe that continued evolution of the project toward developing low-, moderate- and high-water sites at Baird Canyon and Canyon Creek to reduce intra-season variability in catch rates is preferable to simply increasing the overall proportion of the run captured. We intend to continue to refine how the fishwheels are operated at existing sites, as well as explore alternate fishwheel designs that may yield more consistent catch rates across a wide range of water conditions.

The 2004 abundance estimate was both of sufficient accuracy and precision, but it did not address moderate portions of the migratory timing (i.e., prior to 22 May and after June 22, likely ~20% of the migration) or the smallest Chinook salmon (< 600 mm FL). Censoring smaller-sized Chinook salmon, which are typically 2-ocean fish, from mark-recapture experiments is common in Alaska (McPherson et al. 1999; Pahlke et al. 2000; Savereide 2004). It is anticipated that ongoing improvements to fishwheel sites and design will lead to better coverage of the run and help to address these issues.

A common concern when using mark-recapture methods with Chinook salmon, which return over a relatively wide size range compared with other salmon, is that the probability of capture or recapture may vary with body size. Studies have shown that fishwheels can be size-selective for salmon (Meehan 1961; Cappiello and Bruden 1997; Link and Nass 1999); however, it requires tremendous differences in the relative vulnerability across sizes to create a meaningful bias in the abundance estimate (Ricker 1975). Despite relatively large sample sizes in 2004, size selectivity was not detected.

CONCLUSIONS

This year (2004) was the first of three years in a new funding cycle (FY04-06) to operate a long-term Chinook salmon escapement monitoring project on the Copper River. This project follows on from a three-year (2001-2003) study to examine the feasibility of using fishwheels for long-term monitoring of Chinook escapement. Despite the numerous and often significant challenges encountered during this study, it has continued to meet or exceed all project objectives and expectations. Reliable drainage-wide abundance estimates for Chinook salmon have been generated for the past two years and the project has evolved into a long-term monitoring program that has made NVE an integral part of Copper River salmon research. In addition, this project has demonstrated that several agencies (e.g., USFWS, NVE, ADF&G) can work cooperatively to collect valuable data on Copper River salmon stocks that will be used to assess current management practices. Given the success of the project, it appears that fishwheels and mark-recapture methods can be used to estimate the inriver abundance of Chinook salmon on the Copper River well into the future.

RECOMMENDATIONS

In light of the preceding discussion and the fact this project will be funded by the Federal Subsistence Board for at least another two years, the following are recommended for the 2005 field season:

(1) Mobilize half of the Baird Canyon crew around 5 May and the other half on 9 May; mobilize the Canyon Creek crew on 14 May;
(2) Operate one fishwheel at Site 2 and one fishwheel at Site 3 at Baird Canyon;
(3) Build a third subsistence-style fishwheel for Baird Canyon which should operate effectively along the bank adjacent to the cabin, particularly during high-water conditions late in the season;
(4) Operate the newly modified Fishwheel 3 near Site 8;

(5) Continue to operate Fishwheel 4 at Site 8 along the gravel bar upstream of camp;
(6) Continue to use the escape panels in each fishwheel (when possible) with the openings set to a width of 6.5;
(7) If water levels at Baird Canyon are anticipated to rise to levels observed in late June 2004, then fishwheels 1 and 2 should be moved upstream to the cabin before high velocities preclude safely moving the fishwheels out of the canyon;
(8) Improve the demobilization plan for Baird Canyon in order to reduce the amount of time and effort required and the probability of equipment being damaged by snow over the winter; and
(9) Consider constructing a shed adjacent to the Baird Canyon cabin to store the fully assembled baskets from all fishwheels.

ACKNOWLEDGMENTS

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Bruce Cain and Erica McCall Valentine (NVE) assisted with project logistics and reviewed drafts of this report. Dan Valentine (NVE) assisted with pre-season logistics and tasks. Justin Burket helped set up Starband, communication, computer and electrical systems. Michael Link (LGL) was a principal investigator and his contributions were instrumental to the success of this study. In addition to their lead role on the radiotelemetry component of the project, James Savereide and Amy Marsh (ADF&G, Division of Sport Fish, Fairbanks) assisted with fishwheel installation and maintenance, sampling and data collection. Dan Ashe and Steve Moffitt (ADF&G, Commercial Fisheries Division, Cordova) provided valuable inseason fishery information. Johnny Goodlataw (Tazlina) provided technical advice for re-building Fishwheel 4, Lenny Peterson (Peterson Welding and Machine, Cordova) fabricated transoms for Fishwheel 1, and assisted with emergency orders of aluminum tubing for the destroyed baskets at Baird Canyon. Air support was provided by Cordova Air, Fishing and Flying, and Jared Kennedy.

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FIGURES

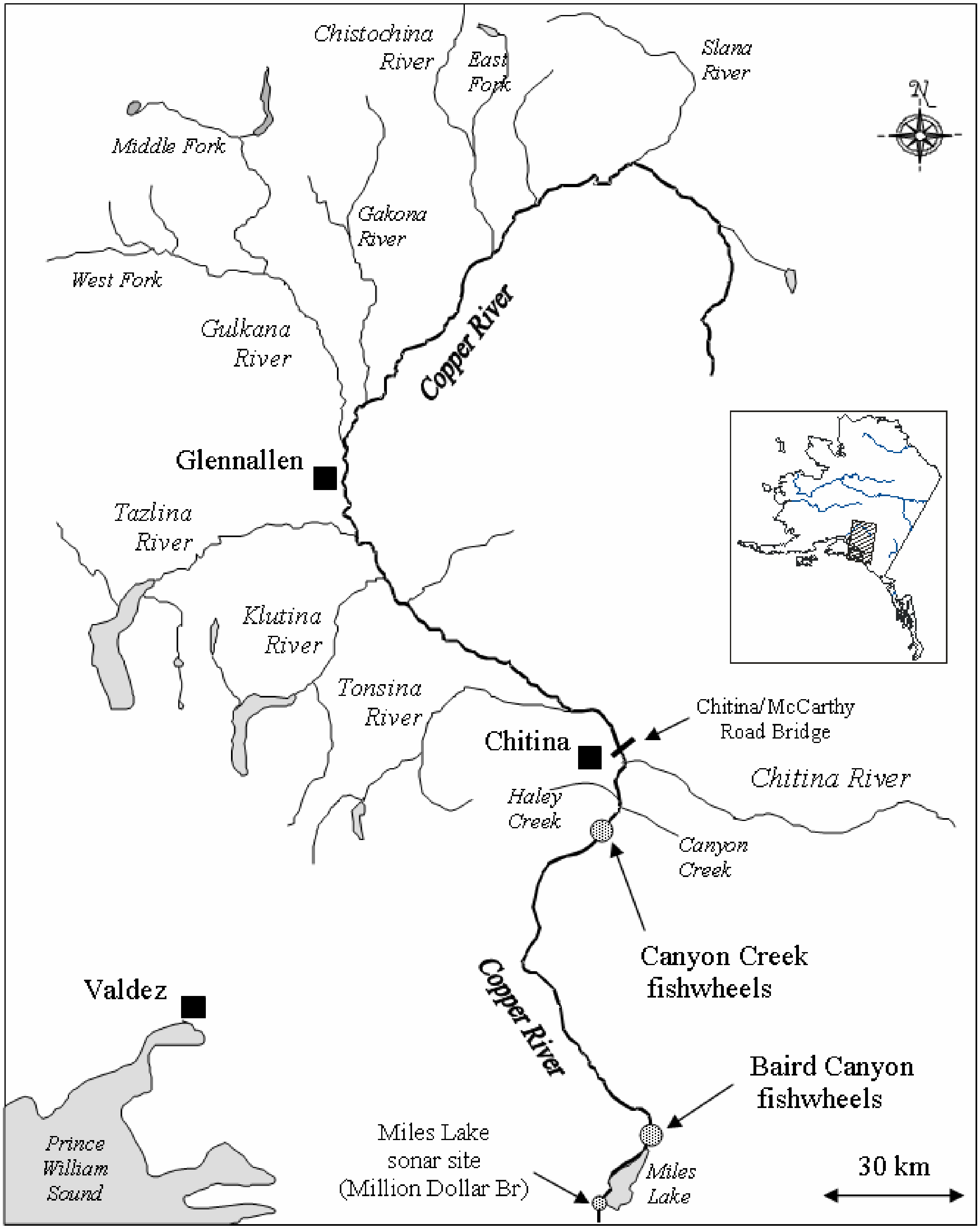


Figure 1. Map of the study area showing the location of the Baird Canyon and Canyon Creek fishwheels on the Copper River in Alaska, 2004.

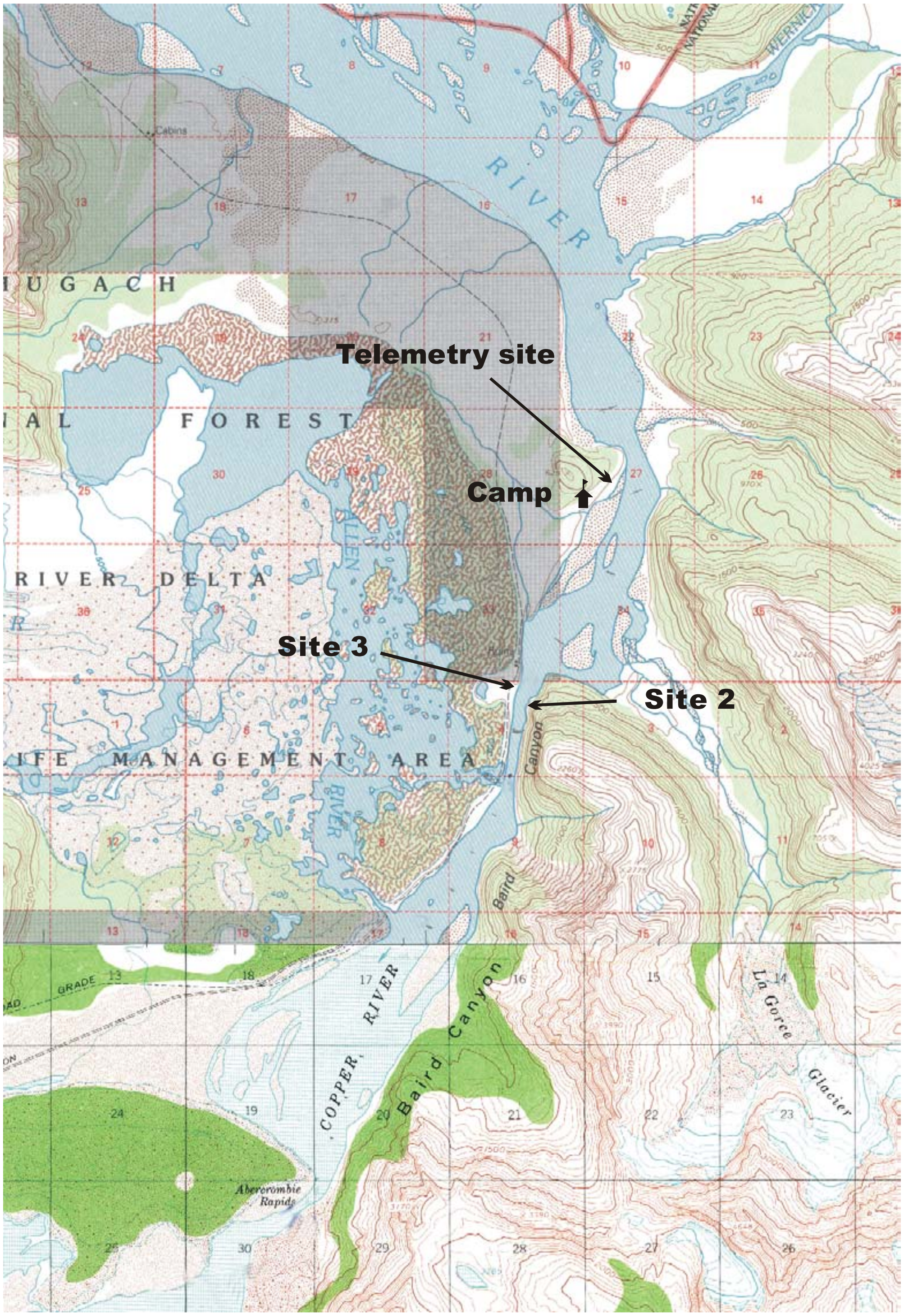


Figure 2. Map of Baird Canyon on the Copper River showing the location of two fishwheel sites used in 2004, the field camp and a telemetry site.

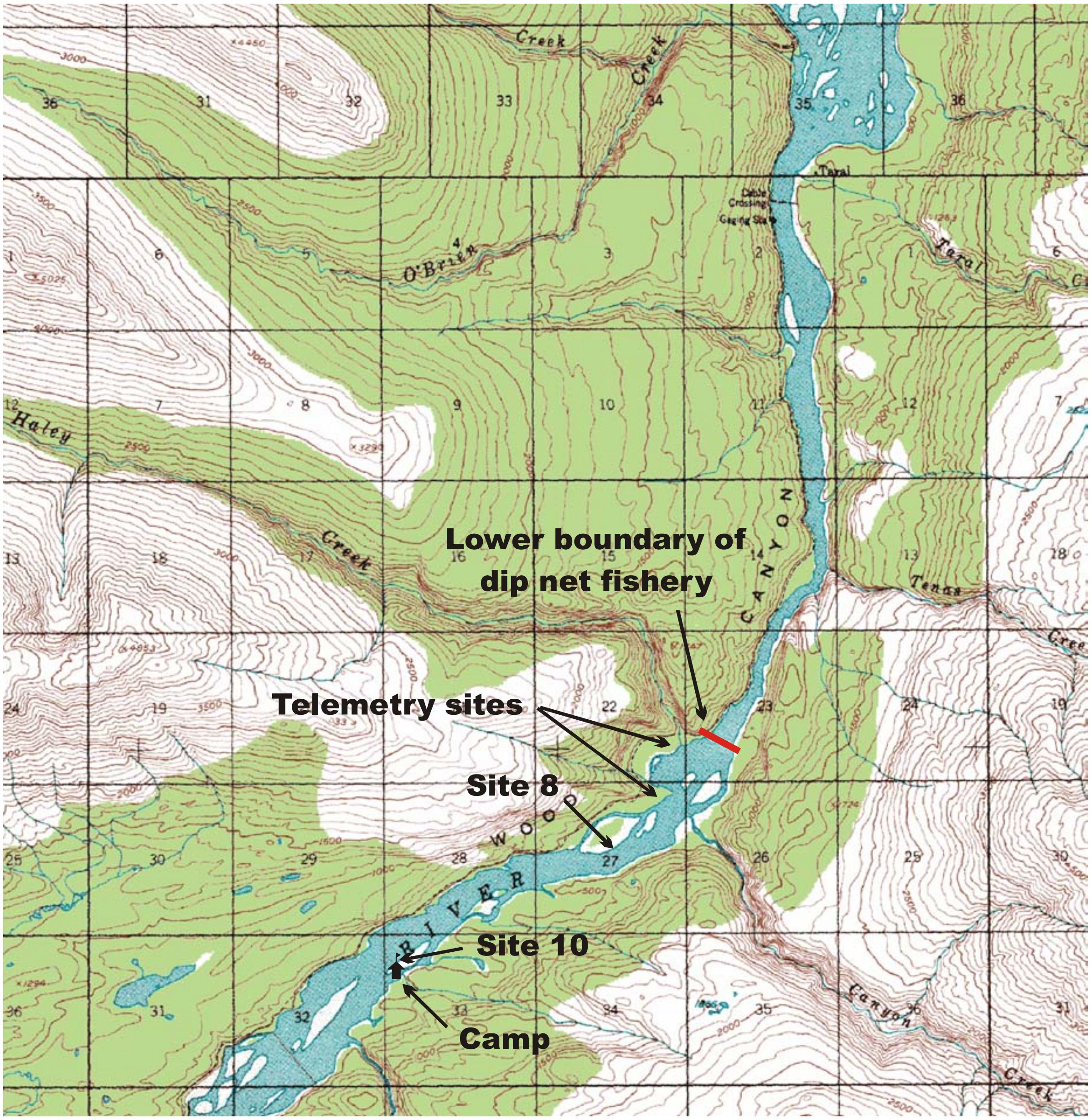
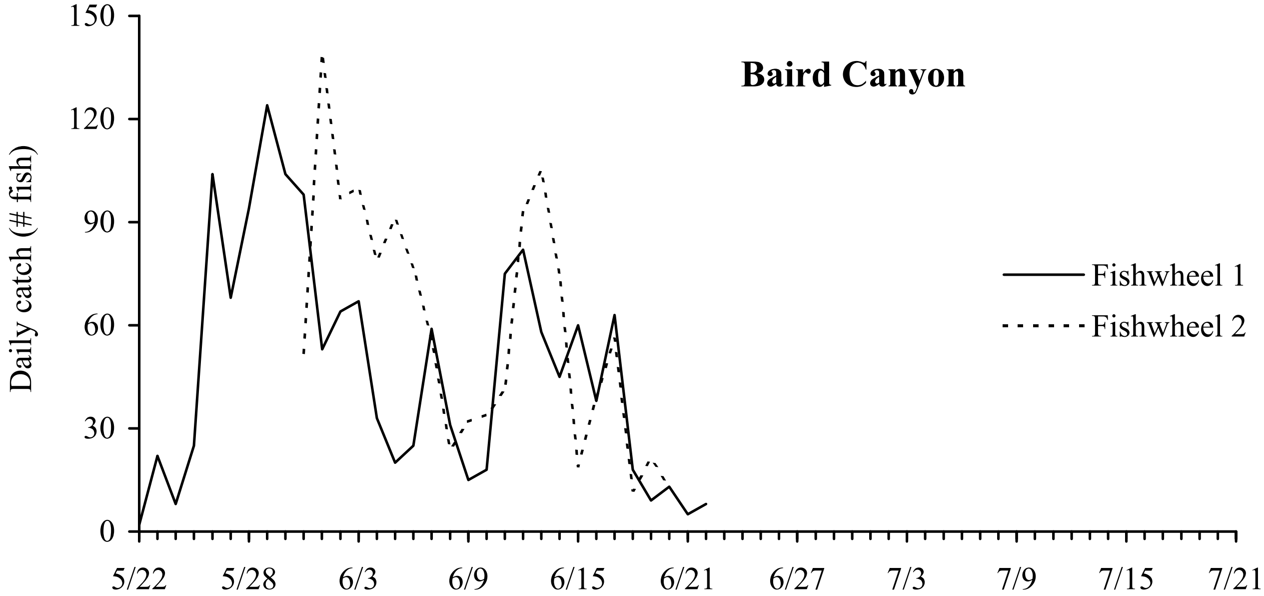


Figure 3. Map of Wood Canyon on the Copper River showing the location of two fishwheel sites used in 2004, the field camp, two telemetry sites and the lower boundary of the Chitina Subdistrict dip net (CSDN) fishery.



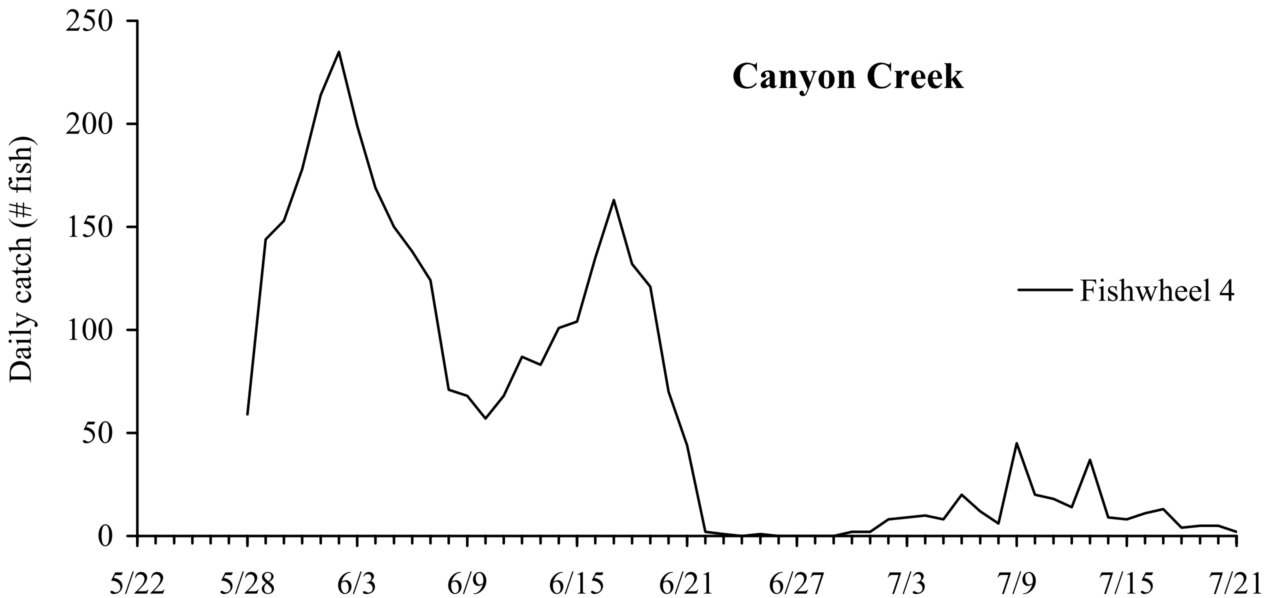
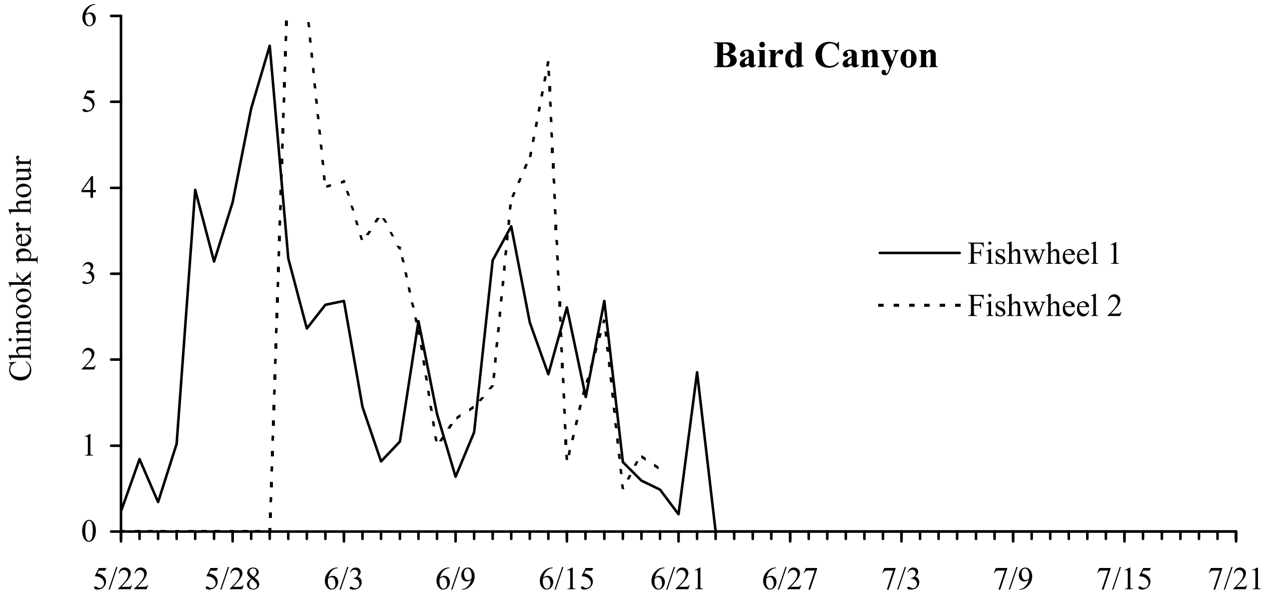


Figure 4. Daily catch of Chinook salmon at the Baird Canyon and Canyon Creek fishwheels on the Copper River, 2004.



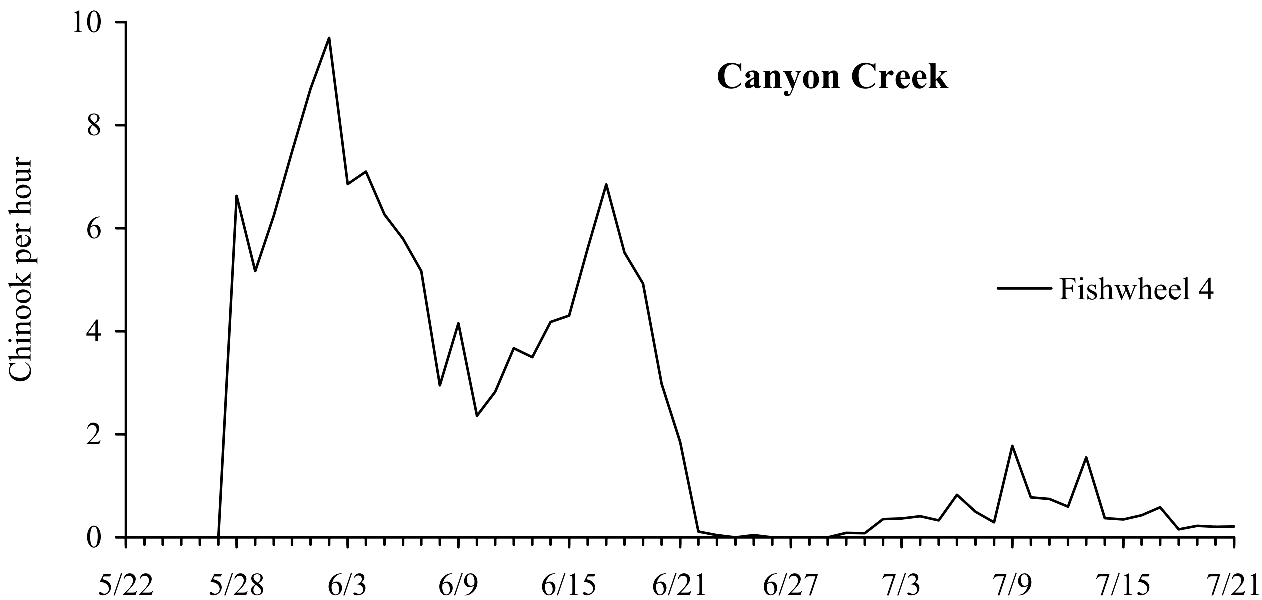


Figure 5. Catch per unit effort (fish per fishwheel hour) for Chinook salmon at the Baird Canyon and Canyon Creek fishwheels on the Copper River, 2004.

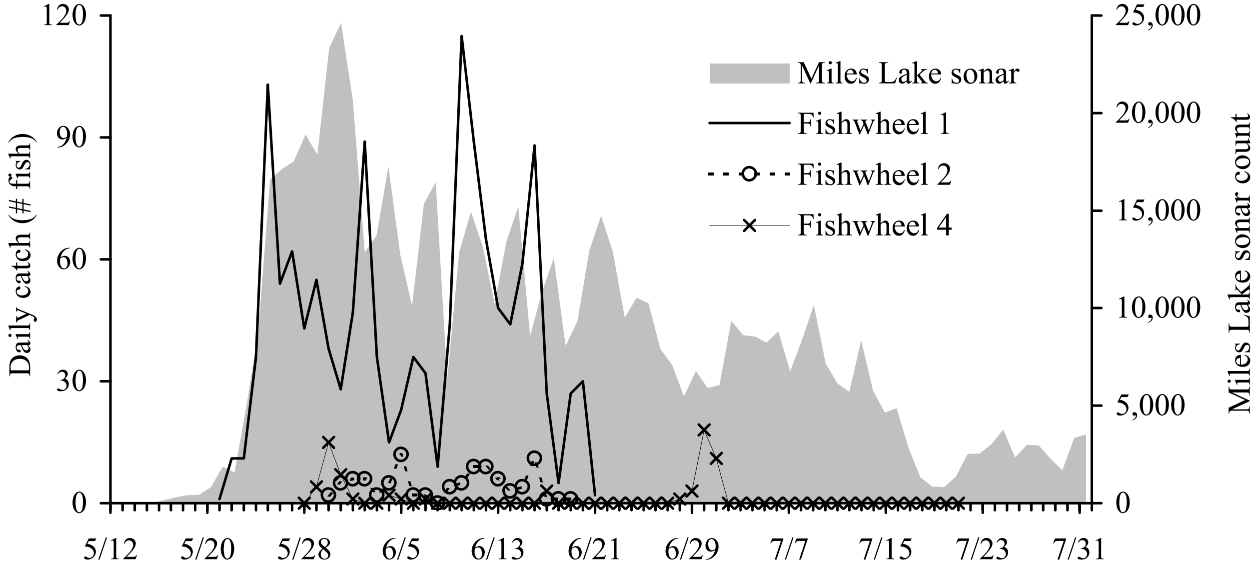


Figure 6. Daily catch of sockeye salmon at the Baird Canyon (FW1 & 2) and Canyon Creek (FW4) fishwheels and the Miles Lake sonar counts, 2004.

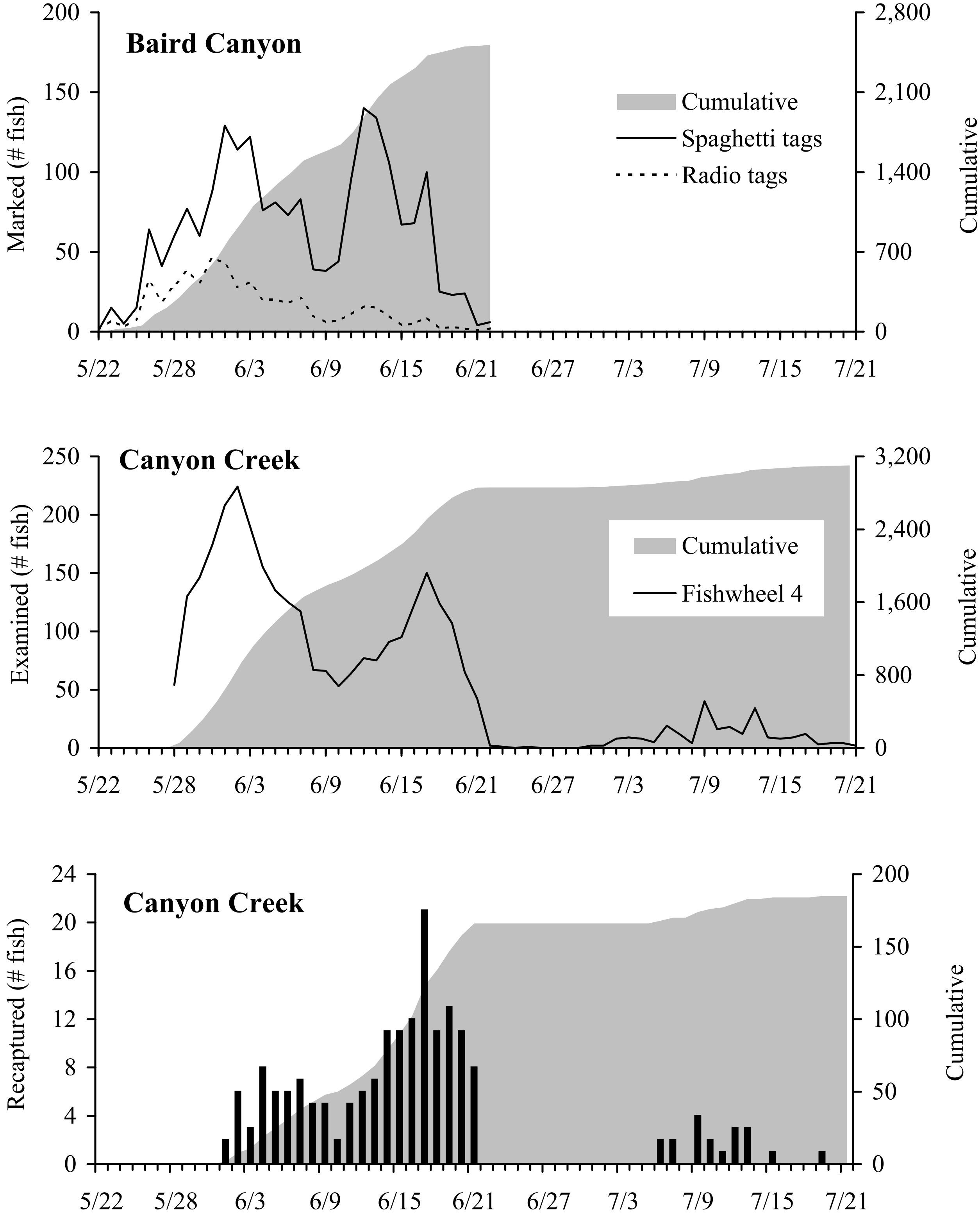


Figure 7. Number of Chinook salmon marked, examined and recaptured at the Copper River fishwheels, 2004.

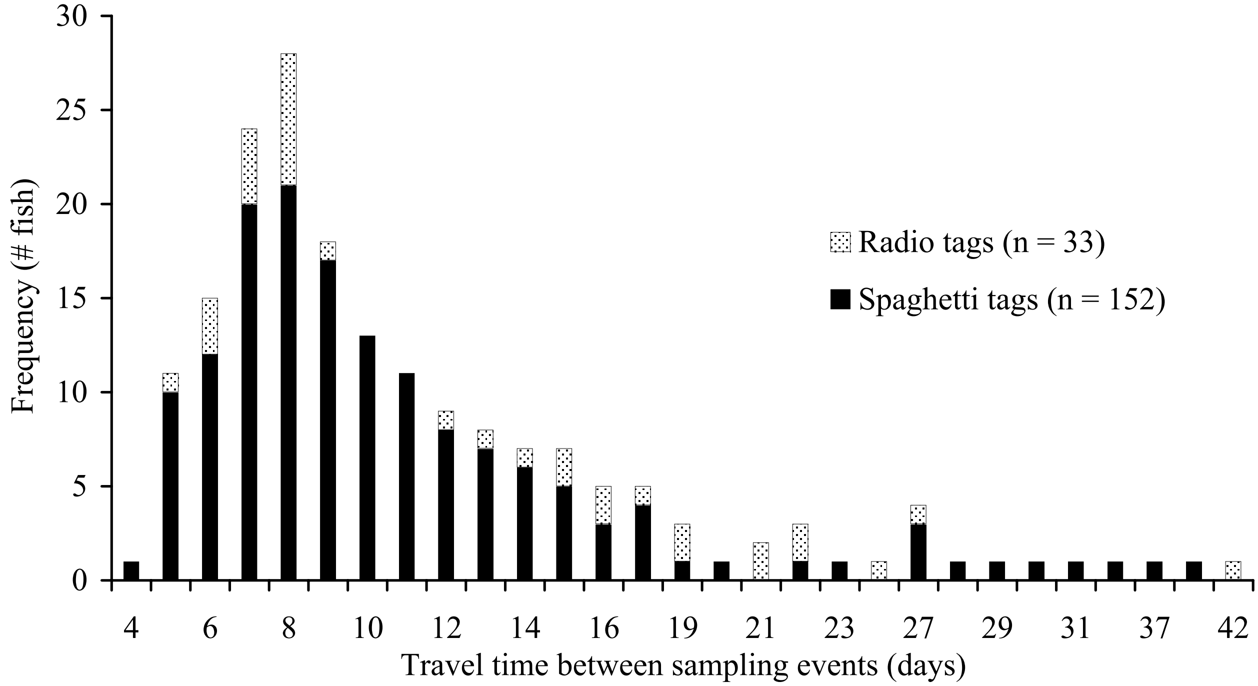


Figure 8. Travel time (days) of Chinook salmon that were tagged at the Baird Canyon fishwheels and recaptured at the Canyon Creek fishwheels, 2004.

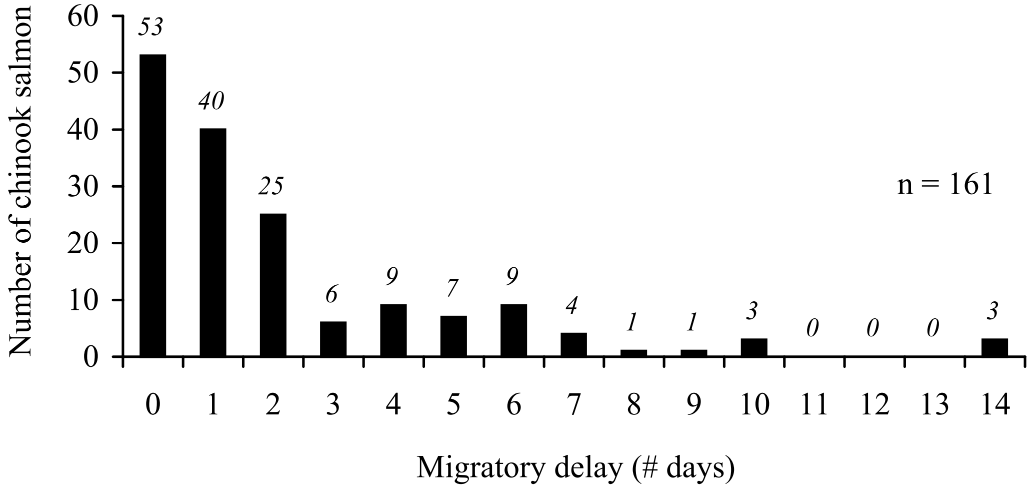


Figure 9. Migratory delay for chinook salmon tagged and recaptured at the Baird Canyon fishwheels, 2004.

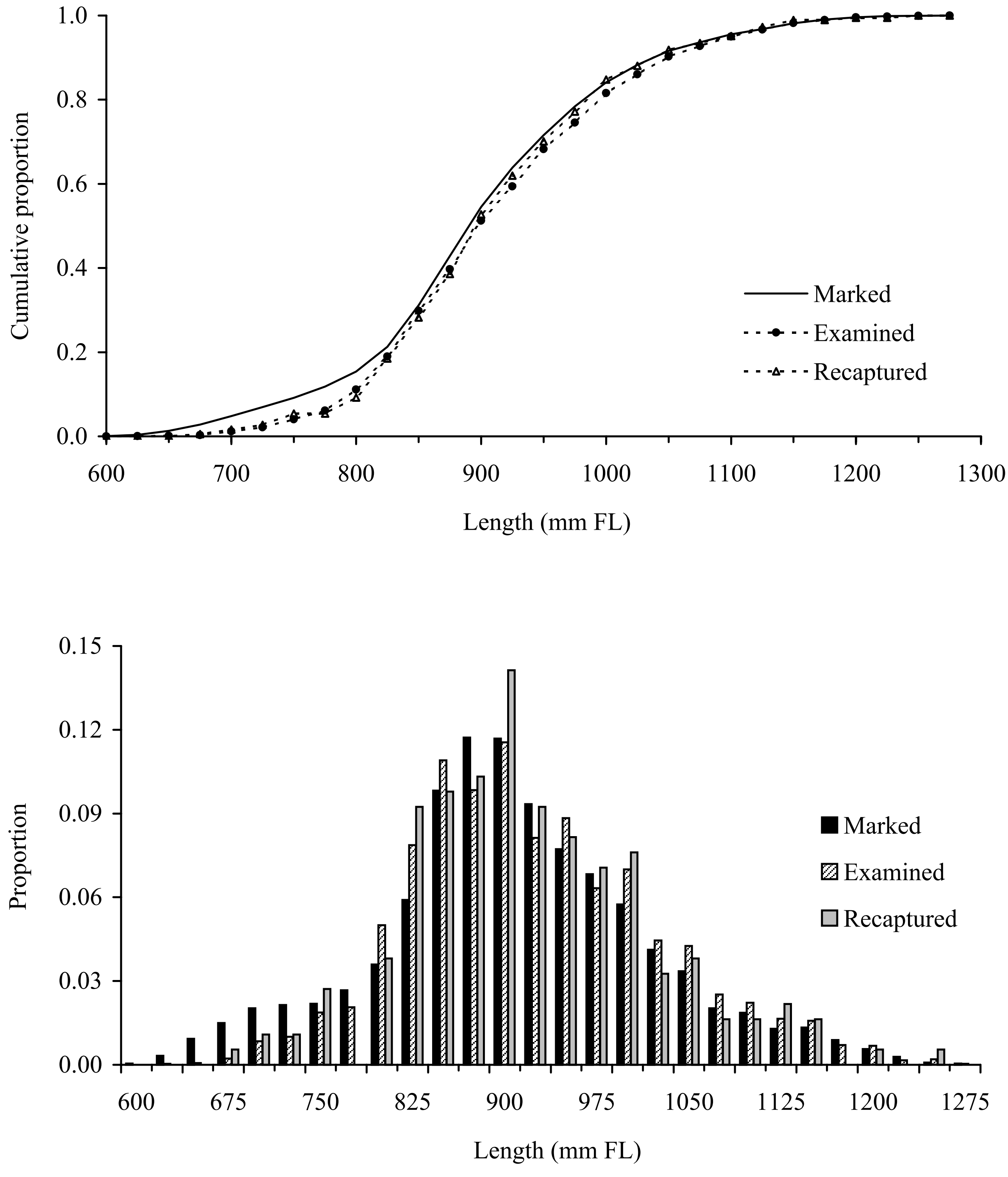


Figure 10. Cumulative length-frequency distributions of Chinook salmon (≥ 600 mm FL) marked at Baird Canyon and examined and recaptured at Canyon Creek, 2004.

TABLES

Table 1. Capture history for Chinook salmon sampled during the first event (Baird Canyon) that were used to estimate inriver abundance, 2004.

Capture history	Fishwheel 1	Fishwheel 2	Total
Total number captured	1,508	1,255	2,763
Untagged fish			
Escaped prior to applying both marks	55	48	103
Visible injury or stress	88	54	142
Coded-wire tag (CWT)	1	0	1
Mortality	0	2	2
Total untagged	144	104	248
Tagged fish (primary & secondary marks)			
Spaghetti tag and right operculum punch	1,059	958	2,017
Radio tag and spaghetti tag	305	193	498
Total tagged	1,364	1,151	2,515
Censored tags			
Radio-tagged fish			
FL < 600 mm FL	0	1	1
Known radio-tag failures [a]	22	14	36
Total radio tags censored	22	15	37
Spaghetti-tagged fish			
FL < 600 mm FL	1	0	1
Total spaghetti tags censored	1	0	1
Total tags censored	23	15	38
Number of fish available for recovery			
Spaghetti tag and right operculum punch	1,058	958	2,016
Radio tag and spaghetti tag	283	178	461
Total available for recovery	1,341	1,136	2,477

[a] Radio-tagged fish that were never detected at or above the Canyon Creek fishwheels.

Table 2. Capture history for Chinook salmon sampled during the second event (Canyon Creek) that were used to estimate inriver abundance, 2004.

Capture history	Fishwheel 4
Total number captured	3,339
Not examined	
Escaped before examination complete	238
Number of fish examined at Canyon Creek	3,101
Recaptures	
Spaghetti tag and right operculum punch	152
Radio tag and spaghetti tag	33
Total	185

Table 3. Capture history for Chinook salmon that were marked and examined at the Copper River fishwheels for which consecutive periods with similar mark and recapture rates were pooled.

Period of marking	Period of recapture: 5/28-6/6	6/7-15	6/16-7/6	7/7-7/21	Recaptured	Marked	Not recaptured	Recapture rate
5/22-29	26	8	2	0	**36**	410	**374**	0.088
5/30-6/4	5	37	20	2	**64**	770	**706**	0.083
6/5-11	0	14	39	3	**56**	541	**485**	0.104
6/12-22	0	0	17	12	**29**	756	**727**	0.038
Recaptured	**31**	**59**	**78**	**17**			χ^2 = 23, df = 3, P = 0.00	
Unmarked	**1,510**	**646**	**590**	**170**				
Examined	1,541	705	668	187				
Mark rate	0.020	0.084	0.117	0.091	χ^2 = 92, df = 3, P = 0.00			

Data used for chi-square tests in bold.

Table 4. Estimated abundance of Chinook salmon measuring 600 mm FL or greater that migrated upstream of Baird Canyon from 22 May to 22 July 2004.

Period of marking	Abundance	P(capture) First Event	Period of recapture 5/29-6/6	6/7-15	6/16-7/6	7/7-7/21
5/22-29	23,981	0.017	17,002	6,443	536	0
5/30-6/4	3,118	0.247	226	2,063	371	458
6/5-11	3,372	0.160	0	1,201	1,114	1,057
6/12-22	10,093	0.075	0	0	1,040	9,053
Total	**40,564**	**(SE = 4,650)**	17,229	9,707	3,061	10,567
P(capture) Second Event			0.0894	0.073	0.218	0.018

APPENDICES

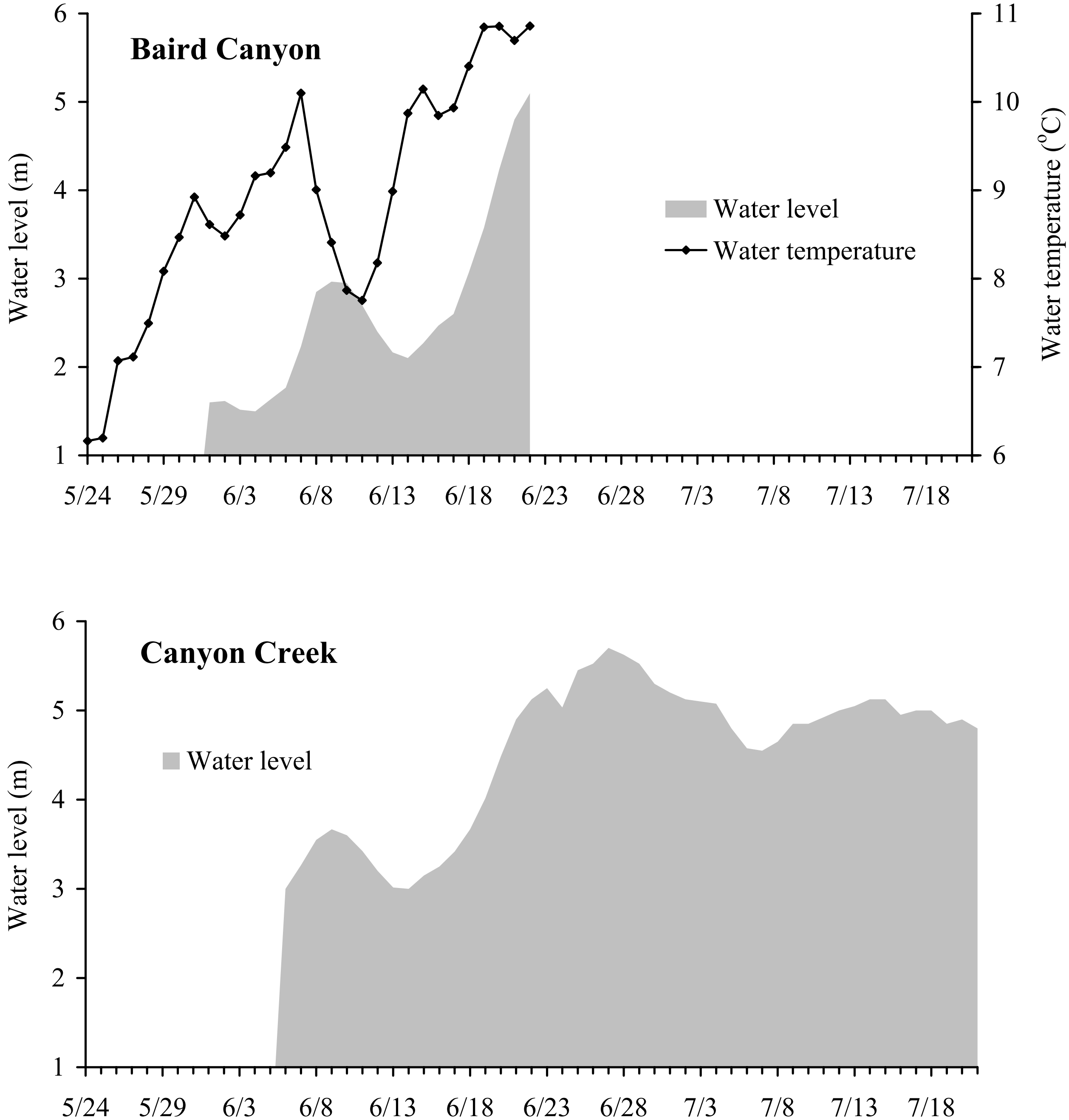


Figure A-1. Average daily water level and water temperature of the Copper River near the Baird Canyon and Canyon Creek fishwheels, 2004.

Table A-1. Average daily water level and water temperature of the Copper River near the Baird Canyon and Canyon Creek fishwheels, 2004.

	Baird Canyon		Canyon Creek
Date	Depth (m)	Temp. (^{o}C)	Depth (m)
24-May		6.2	
25-May		6.2	
26-May		7.1	
27-May		7.1	
28-May		7.5	
29-May		8.1	
30-May		8.5	
31-May		8.9	
1-Jun	1.6	8.6	
2-Jun	1.6	8.5	
3-Jun	1.5	8.7	
4-Jun	1.5	9.2	
5-Jun	1.6	9.2	
6-Jun	1.8	9.5	3.0
7-Jun	2.2	10.1	3.3
8-Jun	2.9	9.0	3.6
9-Jun	3.0	8.4	3.7
10-Jun	3.0	7.9	3.6
11-Jun	2.7	7.8	3.4
12-Jun	2.4	8.2	3.2
13-Jun	2.2	9.0	3.0
14-Jun	2.1	9.9	3.0
15-Jun	2.3	10.1	3.2
16-Jun	2.5	9.8	3.3
17-Jun	2.6	9.9	3.4
18-Jun	3.1	10.4	3.7
19-Jun	3.6	10.8	4.0
20-Jun	4.2	10.9	4.5
21-Jun	4.8	10.7	4.9
22-Jun	5.1	10.9	5.1
23-Jun			5.3
24-Jun			5.0
25-Jun			5.5
26-Jun			5.5
27-Jun			5.7
28-Jun			5.6

Table A-1. Average daily water level and water temperature of the Copper River near the Baird Canyon and Canyon Creek fishwheels, 2004.

	Baird Canyon		Canyon Creek
Date	Depth (m)	Temp. (^oC)	Depth (m)
29-Jun			5.5
30-Jun			5.3
1-Jul			5.2
2-Jul			5.1
3-Jul			5.1
4-Jul			5.1
5-Jul			4.8
6-Jul			4.6
7-Jul			4.6
8-Jul			4.7
9-Jul			4.9
10-Jul			4.9
11-Jul			4.9
12-Jul			5.0
13-Jul			5.1
14-Jul			5.1
15-Jul			5.1
16-Jul			5.0
17-Jul			5.0
18-Jul			5.0
19-Jul			4.9
20-Jul			4.9
21-Jul			4.8
Mean	2.6	8.9	4.5
Median	2.4	9.0	4.9
Max	5.1	10.9	5.7
Min	1.5	6.2	3.0

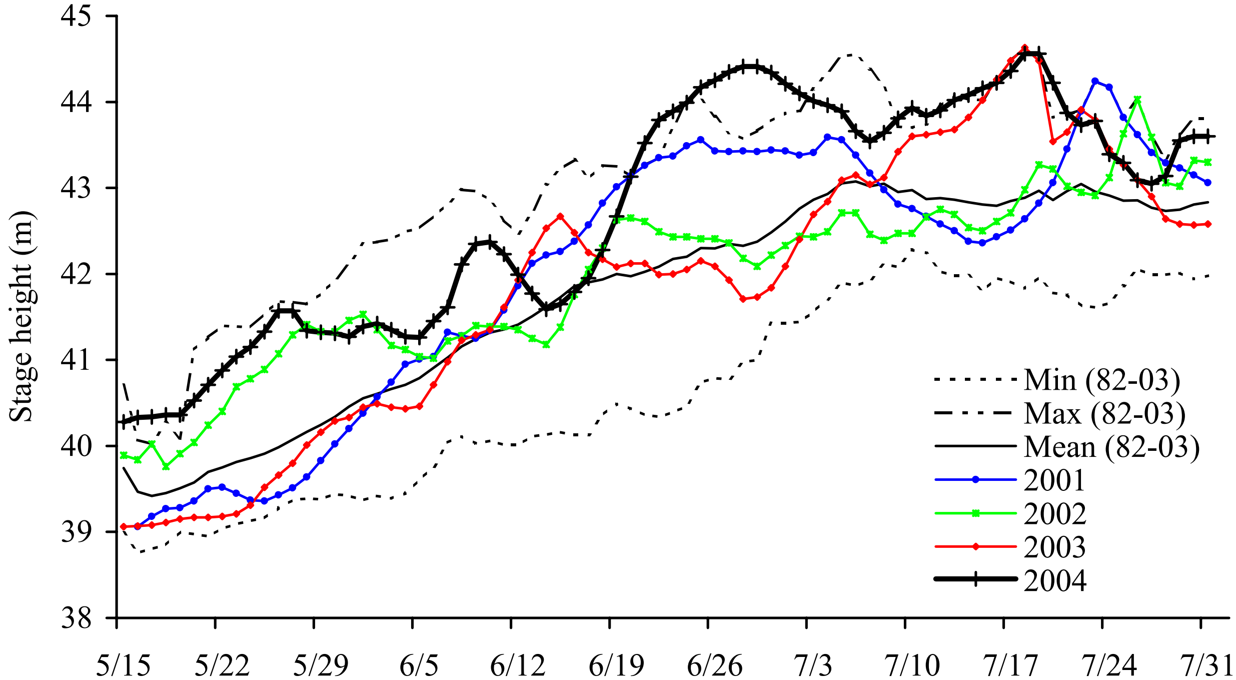


Figure A-2. Stage height of the Copper River at the Million Dollar Bridge, 1982 to 2004.

Table B-1. Description of the sites and operational periods for the fishwheels used on the Copper River, 2004.

Location	FW	Site #	Bank	Operational period From:	Operational period To:	Comments
Baird Canyon	1	2	East	10:30 h 22-May	7:25 h 22-Jun	
	2	3	West	14:50 h 31-May	13:45 h 20-Jun	
Canyon Creek	4	8	West	11:11 h 28-May	18:12 h 7-Jun	
				18:12 h 7-Jun	13:30 h 22-Jun	Moved 2 m downstream
		10	East	19:30 h 22-Jun	11:56 h 5-Jul	Directly in front of camp
				11:56 h 5-Jul	7:47 h 21-Jul	Moved 2 m downstream

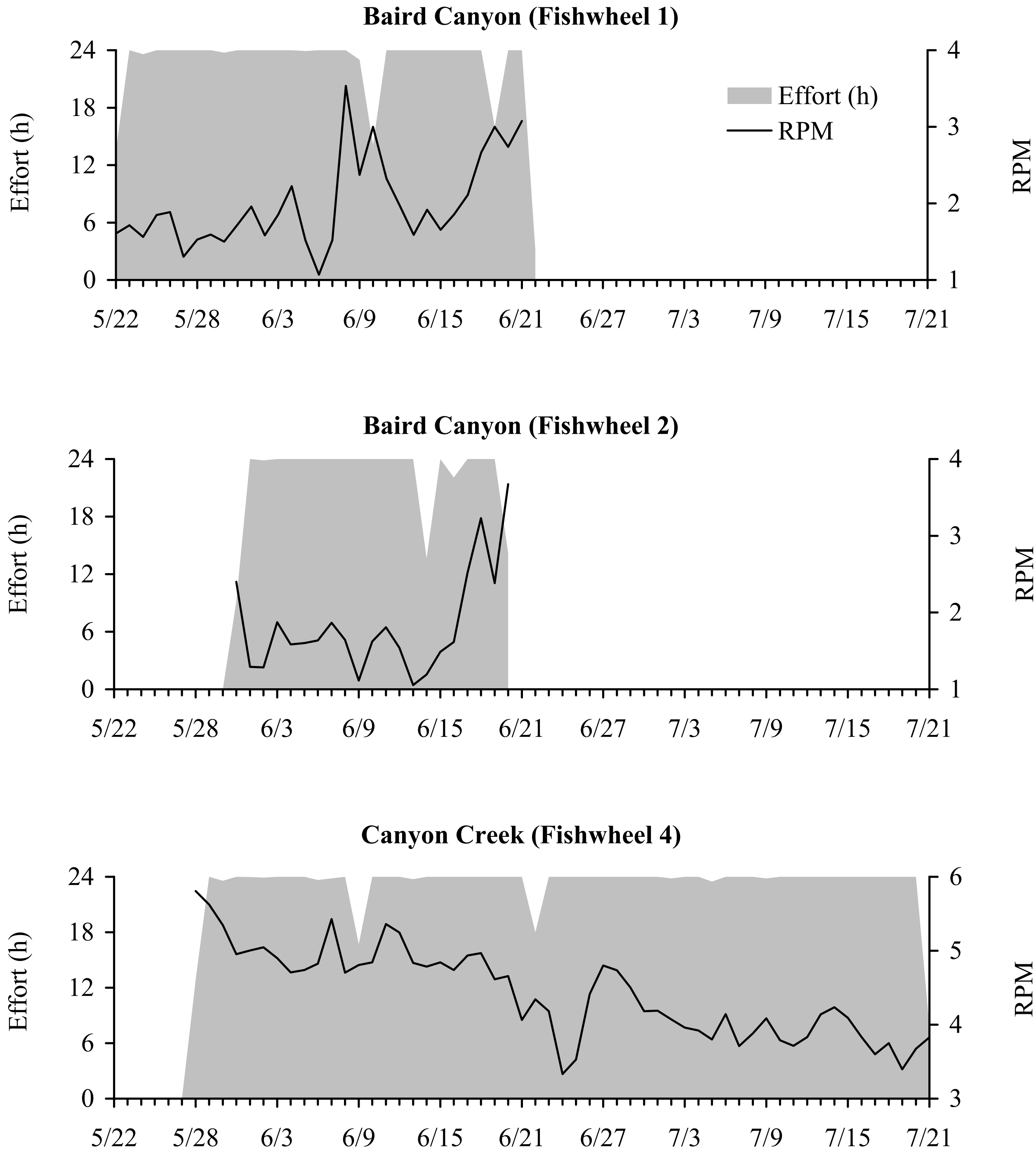


Figure B-1. Fishwheel effort (h) and speed (RPM) at the Baird Canyon and Canyon Creek fishwheels on the Copper River, 2004.

Table B-2. Summary of daily fishwheel effort (h), effort used to calculate catch per unit effort (CPUE), and fishwheel speed (RPM) for the Copper River fishwheels, 2004.

	Fishwheel 1 (Baird Canyon)			Fishwheel 2 (Baird Canyon)			Fishwheel 4 (Canyon Creek)		
Date	Total effort (h)	CPUE effort (h)	RPM	Total effort (h)	CPUE effort (h)	RPM	Total effort (h)	CPUE effort (h)	RPM
22-May	13.5	8.6	1.6						
23-May	24.0	26.1	1.7						
24-May	23.6	23.3	1.6						
25-May	24.0	24.5	1.8						
26-May	24.0	26.2	1.9						
27-May	24.0	21.7	1.3						
28-May	24.0	24.5	1.5				12.8	8.9	5.8
29-May	24.0	25.2	1.6				24.0	27.9	5.6
30-May	23.8	18.4	1.5				23.6	24.5	5.3
31-May	24.0	30.8	1.7	9.2	7.9	2.4	24.0	23.8	5.0
1-Jun	24.0	22.4	2.0	24.0	22.8	1.3	24.0	24.6	5.0
2-Jun	24.0	24.3	1.6	23.9	24.2	1.3	23.9	24.2	5.0
3-Jun	24.0	25.0	1.9	24.0	24.6	1.9	24.0	29.0	4.9
4-Jun	24.0	22.8	2.2	24.0	23.4	1.6	24.0	23.8	4.7
5-Jun	23.9	24.5	1.5	24.0	24.7	1.6	24.0	23.9	4.7
6-Jun	24.0	23.8	1.1	24.0	23.3	1.6	23.7	23.8	4.8
7-Jun	24.0	24.1	1.5	24.0	23.9	1.9	23.8	24.0	5.4
8-Jun	24.0	22.7	3.5	24.0	23.8	1.6	24.0	24.1	4.7
9-Jun	23.0	23.6	2.4	24.0	24.5	1.1	16.7	16.4	4.8
10-Jun	14.1	15.6	3.0	24.0	23.3	1.6	24.0	24.2	4.8
11-Jun	24.0	23.8	2.3	24.0	24.4	1.8	24.0	24.1	5.4
12-Jun	24.0	23.1	2.0	24.0	24.0	1.5	24.0	23.7	5.2
13-Jun	24.0	23.8	1.6	24.0	24.2	1.1	23.8	23.7	4.8
14-Jun	24.0	24.6	1.9	13.7	13.7	1.2	24.0	24.2	4.8
15-Jun	24.0	23.0	1.7	24.0	23.3	1.5	24.0	24.2	4.8
16-Jun	24.0	24.3	1.9	22.1	22.9	1.6	24.0	24.1	4.7
17-Jun	24.0	23.5	2.1	24.0	22.9	2.5	24.0	23.8	4.9
18-Jun	24.0	22.3	2.7	24.0	23.5	3.2	24.0	23.9	5.0
19-Jun	16.0	15.2	3.0	24.0	23.6	2.4	24.0	24.6	4.6
20-Jun	24.0	26.5	2.7	14.2	18.1	3.7	24.0	23.5	4.7
21-Jun	24.0	24.8	3.1				24.0	23.8	4.1
22-Jun	3.1	4.3					18.0	18.1	4.3
23-Jun							24.0	24.0	4.2
24-Jun							24.0	23.8	3.3
25-Jun							24.0	24.6	3.5
26-Jun							24.0	23.2	4.4

Table B-2. Summary of daily fishwheel effort (h), effort used to calculate catch per unit effort (CPUE), and fishwheel speed (RPM) for the Copper River fishwheels, 2004.

	Fishwheel 1 (Baird Canyon)			Fishwheel 2 (Baird Canyon)			Fishwheel 4 (Canyon Creek)		
Date	Total effort (h)	CPUE effort (h)	RPM	Total effort (h)	CPUE effort (h)	RPM	Total effort (h)	CPUE effort (h)	RPM
27-Jun							24.0	24.1	4.8
28-Jun							24.0	24.1	4.7
29-Jun							24.0	23.3	4.5
30-Jun							24.0	23.8	4.2
1-Jul							24.0	25.1	4.2
2-Jul							23.8	22.6	4.1
3-Jul							24.0	24.7	4.0
4-Jul							24.0	24.4	3.9
5-Jul							23.5	24.4	3.8
6-Jul							24.0	24.2	4.1
7-Jul							24.0	24.0	3.7
8-Jul							24.0	20.4	3.9
9-Jul							23.8	25.3	4.1
10-Jul							24.0	25.8	3.8
11-Jul							24.0	24.1	3.7
12-Jul							24.0	23.6	3.8
13-Jul							24.0	23.8	4.1
14-Jul							24.0	24.3	4.2
15-Jul							24.0	23.0	4.1
16-Jul							24.0	25.5	3.8
17-Jul							24.0	22.2	3.6
18-Jul							24.0	25.8	3.8
19-Jul							24.0	22.2	3.4
20-Jul							24.0	24.3	3.7
21-Jul							7.8	9.4	3.8
Effort (h)	717		2.0	467		1.8	1,277		4.4
Effort (d)	29.9			19.5			53.2		
Percent operational:									
	96.7%			97.4%			98.8%		

Table C-1. Total catch and catch per unit effort (Chinook per fishwheel hour) at the Copper River fishwheels, 2004.

	Baird Canyon						Canyon Creek		
	Fishwheel 1			Fishwheel 2			Fishwheel 4		
Date	Catch	Cum.	CPUE	Catch	Cum.	CPUE	Catch	Cum.	CPUE
22 May	2	2	0.2						
23 May	22	24	0.8						
24 May	8	32	0.3						
25 May	25	57	1.0						
26 May	104	161	4.0						
27 May	68	229	3.1						
28 May	94	323	3.8				59	59	6.6
29 May	124	447	4.9				144	203	5.2
30 May	104	551	5.7				153	356	6.2
31 May	98	649	3.2	52	52	6.6	178	534	7.5
1 Jun	53	702	2.4	139	191	6.1	214	748	8.7
2 Jun	64	766	2.6	97	288	4.0	235	983	9.7
3 Jun	67	833	2.7	100	388	4.1	199	1,182	6.9
4 Jun	33	866	1.4	79	467	3.4	169	1,351	7.1
5 Jun	20	886	0.8	91	558	3.7	150	1,501	6.3
6 Jun	25	911	1.0	77	635	3.3	138	1,639	5.8
7 Jun	59	970	2.4	56	691	2.3	124	1,763	5.2
8 Jun	31	1,001	1.4	24	715	1.0	71	1,834	3.0
9 Jun	15	1,016	0.6	32	747	1.3	68	1,902	4.2
10 Jun	18	1,034	1.2	34	781	1.5	57	1,959	2.4
11 Jun	75	1,109	3.2	41	822	1.7	68	2,027	2.8
12 Jun	82	1,191	3.6	93	915	3.9	87	2,114	3.7
13 Jun	58	1,249	2.4	105	1,020	4.3	83	2,197	3.5
14 Jun	45	1,294	1.8	75	1,095	5.5	101	2,298	4.2
15 Jun	60	1,354	2.6	19	1,114	0.8	104	2,402	4.3
16 Jun	38	1,392	1.6	39	1,153	1.7	135	2,537	5.6
17 Jun	63	1,455	2.7	56	1,209	2.4	163	2,700	6.9
18 Jun	18	1,473	0.8	12	1,221	0.5	132	2,832	5.5
19 Jun	9	1,482	0.6	21	1,242	0.9	121	2,953	4.9
20 Jun	13	1,495	0.5	13	1,255	0.7	70	3,023	3.0
21 Jun	5	1,500	0.2				44	3,067	1.9
22 Jun	8	1,508	1.9				2	3,069	0.1
23 Jun							1	3,070	0.0
24 Jun							0	3,070	0.0
25 Jun							1	3,071	0.0
26 Jun							0	3,071	0.0

Table C-1. Total catch and catch per unit effort (Chinook per fishwheel hour) at the Copper River fishwheels, 2004.

	Baird Canyon						Canyon Creek		
	Fishwheel 1			Fishwheel 2			Fishwheel 4		
Date	Catch	Cum.	CPUE	Catch	Cum.	CPUE	Catch	Cum.	CPUE
27 Jun							0	3,071	0.0
28 Jun							0	3,071	0.0
29 Jun							0	3,071	0.0
30 Jun							2	3,073	0.1
1 Jul							2	3,075	0.1
2 Jul							8	3,083	0.4
3 Jul							9	3,092	0.4
4 Jul							10	3,102	0.4
5 Jul							8	3,110	0.3
6 Jul							20	3,130	0.8
7 Jul							12	3,142	0.5
8 Jul							6	3,148	0.3
9 Jul							45	3,193	1.8
10 Jul							20	3,213	0.8
11 Jul							18	3,231	0.7
12 Jul							14	3,245	0.6
13 Jul							37	3,282	1.6
14 Jul							9	3,291	0.4
15 Jul							8	3,299	0.3
16 Jul							11	3,310	0.4
17 Jul							13	3,323	0.6
18 Jul							4	3,327	0.2
19 Jul							5	3,332	0.2
20 Jul							5	3,337	0.2
21 Jul							2	3,339	0.2
Total	1,508			1,255			3,339		

Table C-2. Other fish species captured at the Baird Canyon and Canyon Creek fishwheels on the Copper River, 2004.

	Baird Canyon		Canyon Creek
Species	Fishwheel 1	Fishwheel 2	Fishwheel 4
Sockeye salmon	1,372	96	67
Steelhead	1	0	0
Dolly Varden	0	0	1
Whitefish	1	0	0
Pacific lamprey	0	1	0
Sucker	0	0	2

Table D-1. Number of Chinook salmon tagged, examined and recaptured at the Baird Canyon and Canyon Creek fishwheels on the Copper River, 2004.

	Baird Canyon								Canyon Creek			
	Fishwheel 1				Fishwheel 2				Fishwheel 4			
Date	Spag	Radio	Total	Cum	Spag	Radio	Total	Cum	Exam	Cum	Recap	Cum
22 May	1	1	2	2								
23 May	15	7	22	24								
24 May	5	3	8	32								
25 May	15	8	23	55								
26 May	64	32	96	151								
27 May	41	19	60	211								
28 May	60	29	89	300					54	54	0	0
29 May	77	38	115	415					130	184	0	0
30 May	60	31	91	506					146	330	0	0
31 May	58	30	88	594	30	16	46	46	174	504	0	0
1 Jun	39	10	49	643	90	33	123	169	208	712	2	2
2 Jun	43	12	55	698	71	16	87	256	224	936	6	8
3 Jun	47	12	59	757	75	19	94	350	190	1,126	3	11
4 Jun	22	6	28	785	54	14	68	418	155	1,281	8	19
5 Jun	16	4	20	805	65	16	81	499	135	1,416	6	25
6 Jun	18	4	22	827	55	14	69	568	125	1,541	6	31
7 Jun	42	10	52	879	41	11	52	620	117	1,658	7	38
8 Jun	21	6	27	906	18	4	22	642	67	1,725	5	43
9 Jun	11	2	13	919	27	4	31	673	66	1,791	5	48
10 Jun	16	1	17	936	28	6	34	707	53	1,844	2	50
11 Jun	61	7	68	1,004	34	4	38	745	64	1,908	5	55
12 Jun	64	8	72	1,076	76	8	84	829	77	1,985	6	61
13 Jun	47	5	52	1,128	87	10	97	926	75	2,060	7	68
14 Jun	40	4	44	1,172	66	6	72	998	91	2,151	11	79
15 Jun	49	4	53	1,225	18	0	18	1,016	95	2,246	11	90
16 Jun	33	3	36	1,261	35	2	37	1,053	123	2,369	12	102
17 Jun	50	5	55	1,316	50	4	54	1,107	150	2,519	21	123
18 Jun	16	0	16	1,332	9	2	11	1,118	124	2,643	11	134
19 Jun	6	0	6	1,338	17	3	20	1,138	107	2,750	13	147
20 Jun	12	1	13	1,351	12	1	13	1,151	65	2,815	11	158
21 Jun	4	1	5	1,356					42	2,857	8	166
22 Jun	6	2	8	1,364					2	2,859	0	166
23 Jun									1	2,860	0	166
24 Jun									0	2,860	0	166
25 Jun									1	2,861	0	166
26 Jun									0	2,861	0	166

Table D-1. Number of Chinook salmon tagged, examined and recaptured at the Baird Canyon and Canyon Creek fishwheels on the Copper River, 2004.

	Baird Canyon								Canyon Creek			
	Fishwheel 1				Fishwheel 2				Fishwheel 4			
Date	Spag	Radio	Total	Cum	Spag	Radio	Total	Cum	Exam	Cum	Recap	Cum
27 Jun									0	2,861	0	166
28 Jun									0	2,861	0	166
29 Jun									0	2,861	0	166
30 Jun									2	2,863	0	166
1 Jul									2	2,865	0	166
2 Jul									8	2,873	0	166
3 Jul									9	2,882	0	166
4 Jul									8	2,890	0	166
5 Jul									5	2,895	0	166
6 Jul									19	2,914	2	168
7 Jul									12	2,926	2	170
8 Jul									4	2,930	0	170
9 Jul									40	2,970	4	174
10 Jul									16	2,986	2	176
11 Jul									18	3,004	1	177
12 Jul									12	3,016	3	180
13 Jul									34	3,050	3	183
14 Jul									9	3,059	0	183
15 Jul									8	3,067	1	184
16 Jul									9	3,076	0	184
17 Jul									12	3,088	0	184
18 Jul									3	3,091	0	184
19 Jul									4	3,095	1	185
20 Jul									4	3,099	0	185
21 Jul									2	3,101	0	185
Total	1,059	305	1,364		958	193	1,151		3,101		185	

Only fish that received both a primary and secondary mark, or were examined for both a primary and secondary mark, were included in this table.

Censored tags were not removed from this table (i.e., 36 radio-tag failures, 2 fish < 600 mm and 184 fish examined at Canyon Creek prior to 30 May).

Table E-1. Comparison of recapture rates by tag type at the Canyon Creek fishwheel, 2004.

Recapture history	Tag type: Spaghetti	Tag type: Radio
Recaptured	152	33
Not recaptured	1,864	428
Total available	2,016	461

Chi-square = 0.08; df = 1; P-value = 0.779

Table E-2. Number of Chinook salmon recaptured by bank of release and bank of recapture and the results of a test to compare for equal movement across the river, 2004.

	Bank of release	
Bank of recapture	West	East
West	63	103
East	7	12
Not recaptured	1,066	1,226

Chi-square = 5.19; df = 2; P-value = 0.075

Table E-3. Number of Chinook salmon recaptured by bank of release and the results of a test to compare recapture rates for fish marked on the east and west banks, 2004.

	Bank of release	
History of recapture	West	East
Recaptured	70	115
Not recaptured	1,066	1,226

Chi-square = 5.18; df = 1; P-value = 0.023

PHOTO PLATES

Photo 1. Mobilization at Baird Canyon required digging two fishwheels out of 2 m of snow in early May 2004.

Photo 2. Fishwheel 2 in operation at Site 3 along the west bank of the Copper River near the upper end of Baird Canyon, 2004.

Photo 3. Dan Kennedy releasing a spaghetti-tagged Chinook salmon back into the river at Baird Canyon, 2004.

Photo 4. Fishwheel 4 in operation at Site 8 along the west bank of the Copper River downstream from the mouth of Canyon Creek, 2004.